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OF THE

AMERICAN PHYSICAL SOCIETY

INCLUDING THE

PROGRAMME OF THE

1960 ANNUAL MEETING

AT

NEW YORK, NEW YORK

January 27–30, 1960

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January 27, 1960 Series II, Vol. 5, No. 1, Part I

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1960 Annual Meeting at New York, January 27–30, 1960

THE **1960 Annual Meeting of The American Physical Society will be held at New York** on Wednesday, Thursday, Friday, and Saturday, **January 27–30, 1960.** The American Association of Physics Teachers (hereinafter to be denoted by AAPT) will share in the Ceremonial Session and in the banquet. The headquarters hotel will again be the New Yorker. Holding also to the established habit which there is less than no reason to change, we schedule again the Joint Ceremonial Session for Thursday afternoon, the Business Meeting of our Society for Wednesday afternoon (at 4:45), and the joint banquet of the two Societies for Friday evening.

Yet not everything is the same as it was last year and in the years before. There is a noteworthy change in the sizes and locations of the halls that are offered for some of our sessions. Our Council decided that our terribly crowded Annual Meeting deserves, and our finances justify, the hiring of large halls in places other than the headquarters hotel, and the bigger halls of the New Yorker are now supplemented with other big halls in the Statler-Hilton, while the smallest one among those which we formerly used now has been all but discarded. This is going to require a good deal of walking to and fro between the hotels, but Pennsylvania Station offers a wholly covered route for those who consider the weather inclement. Ten minutes should be allowed for the transit from hall in either hotel to hall in the other, though from hotel door to hotel door it should be not more than a six-minute walk. The size of some of the halls will make the blackboard useless, and in these we intend to install the equipment known as the "vu-graph." By the time this Bulletin appears, all of the speakers will have received a memorandum from our Committee on the Character of Meetings, adjuring them to be intelligible and giving them useful hints on how to prepare, how to speak, and how to use the vu-graphs.

Also we booked more halls than we ever took before, hoping to provide ourselves with ample auditoriums even though we discarded the smallest one; and actually we are holding seven simultaneous sessions (in lieu of the former six) on each of six half-days, while on Thursday morning a special symposium of AAPT takes one of our largest halls; but alas, a sudden unexpected rise of fifty-nine (five sessions worth!) contributed papers over last year's total took away all that we thought we had gained for invited papers, and these are much fewer than we could wish. If this sort of thing goes on, we shall have to take back the smallest hall or set up sessions in parallel with the AAPT's part of the Joint Ceremonial Session, or both.

To repeat: **the official hotel is the New Yorker,** which is at Eighth Avenue and Thirty-fourth Street, a block north of the northwest corner of Penn Station (with which it is connected by underground passage). Manhattan Center is just to the west of the New Yorker, and the Statler-Hilton Hotel is at the northeast corner of Penn Station. Those who have not yet made their room reservations should do so at once, and the form letter on page 91 of this Bulletin is inserted for them to use.

The **registration desk** will be located in the North Ballroom Foyer on the mezzanine floor of the New Yorker—same place as in each of the last three years. Banquet tickets will be sold there up to 6 P.M. on Thursday. There will be blackboards for messages and for notice of change of arrangements should any be needful. Titles of post-deadline papers will be distributed on sheets of paper which will be found at the desk. On Tuesday, from 5 to 10 P.M., there will be a desk for preregistration in the lobby of the hotel.

The **registration fee** stays once more at the modest figure of two dollars. We insist upon registration, and we do not accept messages to be posted for anyone who has not registered.

The **banquet of The American Physical Society and the AAPT** will be held on Friday evening in the Grand Ballroom of the New Yorker. The after-dinner speaker will be G. B. Kistiakowsky of Harvard University, presently Special Assistant to the

President for Science and Technology. Since the banquet is being held on the third day of the meeting, we are not asking for advance reservations. You must, however, buy your tickets not later than 6 P.M. on *Thursday* at the registration desk: the hotel sets places for only 5% more than the number of tickets sold at that time. Your tickets will be held for you if you pay in advance (by check, made out to American Physical Society and mailed to Mrs. Emily Wolf, 335 East 45th Street, New York 17, New York). The price will be $5.00.

Cocktails will be available before the banquet, from 6 P.M., in the Ballroom Foyer and in the Panel Room, but the consumers must pay for these themselves.

The **Joint Ceremonial Session of the two Societies** will be held in Manhattan Center on Thursday afternoon, beginning at 2 P.M. Our retiring President, George E. Uhlenbeck, will deliver his address entitled "Some Recent Progress in Statistical Mechanics." The Oersted Medal of the AAPT will be presented by C. J. Overbeck to someone whose name may not be divulged in this place. The nineteenth Richtmyer Memorial Lecture (last year's was denoted the seventeenth, but this is traceable to a miscounting that began years ago) will be given by J. A. Van Allen, and its title is "Physics in Space."

The **Oliver E. Buckley Solid-State Physics Prize** for 1960 will be awarded at the banquet to Benjamin Lax.

Of **invited papers on the general programme** we draw particular attention to two, given by two officers of the Society—V. F. Weisskopf and S. A. Goudsmit—in honor and memory of the late lamented Wolfgang Pauli. These are allotted to Saturday morning, Session TA. Also there is a full-day Sympsoium on accelerators and on equipment ancillary to accelerators, which is allotted to Friday. To illustrate the difficulties of programme making, I remark that the order of the two half-day sessions is reversed from what one would naturally expect so as to avoid coincidence in time between a paper on a plasma betatron and the Symposium of the Division of Plasma Physics. Apart from these and from the Symposia of the Divisions, very few invited papers appear upon the programme, and this I say again is due to the plethora of ten-minute papers, which compelled the denial of many very worthy proposals.

Our **Divisions** have enriched the programme with half-day symposia. That of electron physics ("DEP") is called "Aspects of the Physical Electronics of Surfaces" and is assigned to Friday afternoon, being Session R. That of solid-state physics ("DSSP") is called "Quantum-Mechanical Tunneling in Solids" and is placed on Thursday morning, being Session JA. The Division of Fluid Dynamics ("DFD") has joined with the nascent Division of Plasma Physics ("DPP") in sponsoring a group of invited papers to be given on Friday morning, being Session M. Also the Division of Fluid Dynamics has joined with the Institute of Aeronautical Sciences in sponsoring a symposium which is indicated as our Session HA on Wednesday afternoon but is otherwise out of our purview. Business Meetings of some of these Divisions are indicated in the Epitome.

The **AAPT** has communicated to us a page about its own programme, which is page 88 of this Bulletin. It bespeaks particular attention for its Thursday-morning programme.

Four hundred and nineteen contributed papers are distributed among thirty-six sessions. This is the record number for a New York meeting and falls but thirty-four short of the all-time record, that achieved in the Spring of 1959 in Washington. This bodes ill for the future and for the prospects of invited papers in particular. Theoretical physics continues to expand, with ninety ten-minute papers this year against eighty last. It was necessary to distribute these among seven sessions, leaving not even one half-day free for invited papers in theoretical physics which should have been spared from competition. Robert Serber again consented to the unrewarded task of arranging them; if some theoretical papers appear in experimental sessions, it is not Serber but the Secretary who is responsible. In the absence of the Deputy Secretary, C. S. Wu gave invaluable aid in the placing of papers on nuclear energy levels, transmutation, scattering, and radioactivity. It has not been easy to set up a scheme to avoid interference between cosmic rays, strange particles, pions, muons, space physics, plasma physics, and fluid dynamics. In fact, it has not been feasible.

The **Business Meeting of The American Physical Society** will be held at 4:45 P.M. on Wednesday in the Grand Ballroom of the New Yorker Hotel, as it was last year and the year before.

The **Council of The American Physical Society** will convene on Tuesday, January 26, at 10:30 A.M. in the building of the American Institute of Physics 335 East 45th Street, unless contrary notice is sent to its members.

The American Institute of Physics will conduct a **Placement Service Register** on the 5th floor of the Hotel New Yorker, January 27–30, 1960. The

Register will be open from 9 A.M. until 9 P.M., Wednesday, Thursday, and Friday, and until noon on Saturday.

Post-deadline ten-minute papers pertaining to very recent achievements of very special importance will be considered for admission to the "special supplementary programme" if the abstracts are received at the office of the Society not later than Friday, January 23. The titles of such as are accepted will be distributed on mimeographed sheets at the registration desk, and the papers may be given under the usual ten-minute rule in Session HB, or perhaps occasionally at the ends of relevant sessions if the relevant sessions are short enough to permit of extension.

Preliminary announcements of the Houston and Detroit meetings appear on page 93 of this Bulletin. On page 96 are published the **calendar of meetings and deadlines** up to the end of next June (incidentally it is now planned to omit the West Coast meeting which normally would be held in the summer of 1960) and below it the **rules and instructions for the preparation of abstracts** which we commend to the attention of every member. Please take special note of the new instructions printed in italics after the older ones and of the admonitions as to times of mailing of abstracts which are printed under the calendar. The By-Laws of our Society say "No contributed paper shall be accepted . . . unless the title and an abstract of the paper are in the hands of the Secretary at the closing date stated in the printed call for that meeting." It is extremely hard for a soft-hearted Secretary to enforce this By-Law rigorously when the postmark of the envelope containing the abstract indicates that it just *might* have made the deadline if the postoffice had functioned rapidly; but any clemency is punished by delay in the appearance of the Bulletin, since it takes all of Saturday and Sunday to arrange the on-time abstracts for a big meeting. Consider that the By-Law will be stringently enforced for the Washington meeting and is likely to be stringently enforced for any other.

The **American Institute of Physics** desires us to announce that it will begin in February, 1960, the publication of a new bimonthly journal, The *Journal of Mathematical Physics;* the editor will be Elliott Montroll. This is intended for new mathematical methods for the solution of physical problems and also for original research in physics furthered by such methods. Occasionally it will contain review papers on mathematical topics for physicists.

Errata pertaining to the contents of this issue will be published in a later issue of this Bulletin if received not later than Monday, February 1, by Miss Ruth Bryans, American Institute of Physics, 335 East 45th Street, New York 17, New York. Do not send in a copy of your abstracts marked with corrections! Write out every correction in the form "Instead of . . . read. . . ." Add nothing.

KARL K. DARROW
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE 1960 ANNUAL MEETING

(Personal names are those of invited speakers.)

Wednesday Morning

9:45	A.	Theoretical physics I: statistical theory. New Yorker Boston Room.
10:30	B.	Helicity; radioactive nuclei I. Statler-Hilton Gold Ballroom.
10:00	BA.	Strange particles. New Yorker Grand Ballroom.
9:45	C.	Cryogenics. Statler-Hilton Skytop Room.
10:00	CA.	Optical physics; general physics I. New Yorker Panel Room.
11:00	D.	Johnson, J. H. Reynolds. New Yorker Terrace Room.
10:30	DA.	Neutron physics I, mainly apparatus. Statler-Hilton Penn Top South.

Wednesday Afternoon

2:00	E.	Neutron physics II. Statler-Hilton Penn Top South.
2:00	F.	Radioactive nuclei II. Statler-Hilton Gold Ballroom.
2:00	FA.	Cosmic rays. New Yorker Grand Ballroom.
2:00	G.	Metals; dislocations; radiation damage. Statler-Hilton Skytop Room.
2:00	GA.	General physics II. New Yorker Panel Room.
2:00	H.	Theoretical physics II: nuclear theory. New Yorker Boston Room.
2:00	HA.	Institute of Aeronautical Sciences and Division of Fluid Dynamics: Tani, Stewartson, Germain, Lunc. Hotel Astor, North Ballroom.

Wednesday Afternoon

4:45 Business Meeting of American Physical Society. New Yorker Grand Ballroom.

Thursday Morning

9:30	HB.	Post-deadline papers, if any. Empire Suite.
9:30	I.	Neutron physics III. Statler-Hilton Penn Top South.
9:30	IA.	Theoretical physics III: nuclear theory. New Yorker Boston Room.
9:30	J.	General nuclear physics. Statler-Hilton Ivy Suite.
9:45	JA.	DSSP Symposium: Price, Chynoweth, Hall; Anderson. Statler-Hilton Grand Ballroom.
9:15	K.	Mechanical properties of solids. New Yorker Panel Room.
9:30	KA.	Fluid dynamics; Business Session of DFD. New Yorker Terrace Room.

Thursday Afternoon

2:00 L. Joint Ceremonial Session of APS and AAPT: Uhlenbeck, Overbeck, Van Allen. Manhattan Center.

Friday Morning

9:15	M.	DFD and DPP: Alfven, Chapman, Grad, Rosenbluth. New Yorker Grand Ballroom.
9:30	MA.	Nuclear reactions and energy levels I. Statler-Hilton Penn Top South.
10:30	N.	Space physics. New Yorker Terrace Room.
9:45	NA.	General solid-state physics. Statler-Hilton Ivy Suite.
9:30	O.	Theoretical physics IV: Dispersion and spectral theory. New Yorker Boston Room.
9:45	OA.	Moszkowski, Moravcsik, Weneser, Van Patter. Statler-Hilton Skytop Room.
9:45	P.	Equipment ancillary to accelerators: G. T. Reynolds, Bradner, Courant, Fitch. Statler-Hilton Grand Ballroom.

Friday Afternoon

2:00 PA. Accelerators: Panofsky, Judd, O'Neill, Rogers. Statler-Hilton Grand Ballroom.

2:00 Q. Gupta; theoretical physics V: relativity, baryon interactions. New Yorker Boston Room

2:00 QA. Atkins, Sachs, Button, Piccioni. New Yorker Terrace Room.

2:00 R. DEP Symposium: Johnson, Kisliuk, Laponsky, Soshea, Wehner: Business Meeting of DEP. New Yorker Grand Ballroom.

2:15 RA. Nuclear reactions and energy levels II. Statler-Hilton Penn Top South.

2:00 S. Ferroelectricity and magnetism. Statler-Hilton Ivy Suite.

2:00 SA. Semiconductors I, mostly theory; Friedland. Statler-Hilton Skytop Room.

Friday Evening

7:00 Banquet of APS and AAPT; Kistiakowsky. New Yorker Grand Ballroom.

Saturday Morning

9:30 T. Semiconductors II. Statler-Hilton Skytop Room.

9:30 TA. Symanzik, Lee. Memorial to Wolfgang Pauli: Goudsmit, Weisskopf. Statler-Hilton Grand Ballroom.

9:15 U. Theoretical physics VI: quantum mechanics. New Yorker Boston Room.

9:30 UA. Nuclear reactions and energy levels, III. Statler-Hilton, Penn Top South.

9:15 V. Electron physics. New Yorker Grand Ballroom.

9:30 VA. Pions. Statler-Hilton Ivy Suite.

9:30 W. Pound, Rainwater, Hughes, Brockhouse. New Yorker Terrace Room.

Saturday Afternoon

1:30 WA. Magnetic resonance. New Yorker Panel Room.

1:30 X. Muons; high-energy scattering. New Yorker Terrace Room.

1:30 XA. Nuclear reactions and energy levels IV. Statler-Hilton Penn Top South.

1:30 Y. Semiconductors III. Statler-Hilton Ivy Suite.

1:30 YA. Plasma physics. New Yorker Grand Ballroom.

1:30 Z. Theoretical physics VII: field theory. New Yorker Boston Room.

PROGRAMME

WEDNESDAY MORNING AT 9:45

New Yorker Boston Room

(HAROLD GRAD presiding)

Theoretical Physics I: Statistical Theory

A1. Theory as Wit. JEROME ROTHSTEIN, *Edgerton, Germeshausen and Grier, Inc.*—Theory organizes experience (i.e., product-space of relevant observables involved in a law has informational measure larger than that of subspace compatible with the law; the decrease is organization or information entailed by the law).[1,2] Initial impact of new theory stems (at least partly) from economical expression of unexpected associations between observables not previously connected; "elegance" and enjoyment of new vistas arise from same source. Freud demonstrated how association enters into errors, dreams, and wit, and their relation to the unconscious[3]; impact of wit often stems from introduction of unexpected associations economically expressed (e.g., bon vivant's alcoholidays or old man's anecdotage). Theory is thus wit, in a sense, ditto creative work generally. As with wit, the bolder the correlations introduced, the greater the enjoyment (subject to constraint of experiential validation without which theory or joke falls flat). Earlier thoughts on motivation of theory[2] fit in with a common unconscious source for dreams, wit, theory, and creation.

[1] J. Rothstein, *Communication, Organization, and Science* (Falcon's Wing Press, Indian Hills, Colorado, 1958). The author disclaims responsibility for the foreward, included by the publisher without his knowledge.
[2] J. Rothstein, Rev. intern. philosophie **40**, 211 (1957).
[3] *The Basic Writings of Sigmund Freud*, translated by A. A. Brill (The Modern Library, New York, 1938).

A2. Theory of the Correlation Function. E. W. HART, *General Electric Research Laboratory.*—A self-consistent phenomenology has been developed for deducing the pair correlation function for a fluid, especially near a critical point. All quantities in the treatment are unambiguously defined as thermodynamic parameters. The relationships of this treatment to that of Ornstein and Zernike and that of von Smoluchowski will be discussed. The exact integral equation will be presented that is satisfied by the correlation function. It will be shown that the Ornstein-Zernike equation is an approximation to this equation when the superposition approximation is employed. The present treatment predicts an oscillatory behavior for the correlation function for material in the interface between the two phases at temperatures just below the critical temperature. A strong effect due to interactions with the container walls also will be shown. Both these phenomena are new and have not been observed previously, nor looked for.

A3. Model for the Study of Brownian Motion. ROBERT J. RUBIN, *National Bureau of Standard.*—The system discussed is a modification of the usual model of an n-dimensional cubic crystal lattice with nearest-neighbor central and noncentral forces. The modification is produced by increasing the mass m of one of the particles to M. It follows from the formal solution of the dynamical equations of motion of the lattice that the velocity of the heavy particle is expressed as a linear combination of the velocities and positions of the light particles. If it is assumed that the initial velocities and the relative positions of the light particles are normally distributed, as in thermal equilibrium, then the time-dependent probability distribution function for the velocity of the heavy particle is normally distributed about the ensemble average velocity $\langle v(\tau)\rangle$ of the heavy particle [$\langle v(0)\rangle = v(0)$, the initial velocity]. The dispersion $\langle \sigma^2(\tau)\rangle$ increases from zero to the thermal value. Simple expressions are obtained for $\langle v(\tau)\rangle$ and $\langle \sigma^2(\tau)\rangle$ for the one- and two-dimensional lattices in the limit $M \gg m$. In the one- and two-dimensional cases $\langle v(\tau)\rangle$ is, respectively, a damped exponential[1] and a damped oscillating exponential.

[1] R. J. Rubin, *Proceedings of International Symposium on Transport Processes in Statistical Mechanics, August, 1956* (Interscience Publishers, Inc., New York, 1958), p. 155.

A4. Fluctuations from the Nonequilibrium Steady State. M. LAX, *Bell Telephone Laboratories.*—Noise (the spectrum of fluctuations) in a steady state possibly far from equilibrium is treated by assuming only that the physical system is, in an appropriate set of variables, Markoffian, stationary, and quasi-linear. The last restriction is partly removed by an analysis of slightly nonlinear systems and completely removed by a treatment of fluctuations in distribution functions. The equilibrium relations of Einstein, Onsager, and Nyquist are shown to exist in modified form in the nonequilibrium case. The Langevin noise-source viewpoint appears in our theory as a consequence rather than as an assumption. The validity of the circuit viewpoint based on Thevenin's theorem is derived for the equilibrium case and shown to require modification in the nonequilibrium case. The meaning of fluctuations in intensive variables is clarified. A set of coupled oscillators is used as an example of a system possessing inertia and some variables that are odd under time reversal. The Hill-van Vliet treatment of ambipolar drift of carrier-concentration fluctuations is used to provide a continuous-parameter example. The assumption that fluctuations at one time but at different places are uncorrelated is derived as part of a general treatment of fluctuations in distribution functions.

A5. Wave Mechanical Modifications of the Equation of State of an Electron Gas. HUGH E. DEWITT, *University of California, Livermore.*—The formal expression obtained by various authors[1] for the sum of the ring interactions in the expansion of the quantum mechanical partition function has been partially evaluated for a high temperature electron gas. In this work the electrons have been treated as distinguisable so that Maxwell-Boltzmann statistics apply, and hence the corrections to the classical Debye-Hückel term in the equation of state are due to the wave nature of the particles. The magnitude of these "diffraction" corrections depends on a parameter, $\gamma = \lambda_{th}/\lambda_0$ where $\lambda_{th} = \hbar/(2mkT)^{\frac{1}{2}}$ is the thermal de Broglie wavelength, and $\lambda_0 = (kT/4\pi e^2\rho)^{\frac{1}{2}}$ is the classical Debye screening length. The Debye-Hückel term is multiplied by a function of γ with a power series expansion in γ containing both even and *odd* powers of γ. The even powers of γ are essentially modifications of the interactions of electrons in distant encounters in a screened Coulomb field. The odd powers of γ arise from close encounters and the assumption that the electrons are point charges. The relationship of these results for the electron gas to the Wigner-Kirkwood expansion[2] of thermodynamic functions in powers of $\hbar^2$ will be discussed.

[1] E. W. Montroll and J. C. Ward, Phys. Fluids **1**, 55 (1958); R. Abe, Progr. Theoret. Phys. **21**, 941 (1959); H. E. DeWitt, Thermodynamic functions of a partially degenerate fully ionized gas, UCRL Rept. No. 5652.
[2] J. G. Kirkwood, Phys. Rev. **44**, 31 (1933).

A6. Singlet and Pair Distributions in a Fluid. J. L. LEBOWITZ,* *Yeshiva University*, AND H. L. FRISCH, *Bell Telephone Laboratories*.—We have investigated the solution of the Fokker-Planck equation suggested by Kirkwood for distribution functions in a liquid. We used both the Chapman-Enskog and the Grad moment method of approximation and found that they yield identical results for the one particle distribution when the deviation from local equilibrium is expressed in terms of the stress and the heat flux. The distribution has then just the form of Grad's solution of the Boltzmann equation. This distribution maximizes the entropy subject to the requirement that the local hydrodynamic variables have certain specified values. Alternatively when expressed in terms of the strain and the temperature gradient the distribution maximizes a combination of the entropy and entropy production. The two particle distribution was found by the Chapman-Enskog method. This distribution too results (at least for the case of pure heat flow) from an N-particle distribution which maximizes the entropy subject to constraints on the combination of entropy and entropy production. We shall also discuss the form of the force term appearing in the two particle equation.

* Supported by the U. S. Air Force Office of Scientific Research.

A7. Free Energy and Phase Transitions in Fluids from the Convolution Approximation. EMMANUEL MEERON, *Boeing Scientific Research Laboratories*.—The convolution approximation results from summing, in the exact cluster expansion of the radial distribution function, all graphs which can be completely evaluated by repeated convolutions. The resulting integral equation yields an approximate "convolution distribution function." The corresponding procedure in the cluster expansion of free energy yields relatively simple formulas involving the convolution distribution function. The convolution approximation is seen to be consistent with the Ornstein-Zernike equation for the direct correlation function (which correlates density fluctuations in fluids), and thus also with the formulas for isothermal compressibility. Owing to this feature, the convolution approximation may permit a simple treatment of first-order phase transitions. The interpretation of the convolution approximation in terms of interparticle potentials is discussed.

A8. Low-Lying Excitations in a Bose Gas of Hard Spheres.* F. MOHLING, *Columbia University* AND A. SIRLIN, *New York University*.—The pseudopotential method has been used to calculate the low-lying excitation energies of a Bose gas of hard spheres at $T=0$ to an order beyond that previously calculated by this technique.[1] The results are in agreement with those obtained by Beliaev[2] using a different approach. The phonon velocity is found to be equal to the velocity of compressional waves to the order of approximation considered. The lifetime of the excitations becomes extremely long as the momentum goes to zero. The generalization for T less than the critical temperature of the Bose gas is being studied.

* Work supported in part by the U. S. Atomic Energy Commission and in part by the Office of Naval Research.
[1] Lee, Huang, and Yang, Phys. Rev. **106**, 1135 (1957).
[2] S. T. Beliaev, Soviet Phys. JETP **7**, 299 (1958).

A9. Application of the Fluctuation-Dissipation Theorem to Kinetic Theory. ABNER SHIMONY, *Princeton University*.—If the interaction Hamiltonian of a system with an external field is sufficiently small, then the fluctuation-dissipation theorem provides an expression for the power dissipated by the system into a heat reservoir. This expression allows a simple calculation of the rate of energy dissipation in several cases of a problem considered by Wang Chang and Uhlenbeck,[1] in which a harmonically bound particle is driven by an alternating field and collides with the molecules of a surrounding gas. Furthermore, it yields a theoretical explanation of a sum rule which these authors had discovered by inspection.

[1] C. S. Wang Chang and G. E. Uhlenbeck, "The kinetic theory of a gas in alternating outside force fields," University of Michigan Engineering Research Institute Tech. Rept. 1956.

A10. Relationship between Systems of Impenetrable Bosons and Fermions in One Dimension.* M. GIRARDEAU, *Brandeis University*.—A rigorous correspondence is established between the energy eigenfunctions of one-dimensional systems of bosons and of spinless fermions with an arbitrary interaction having an impenetrable core. The energy spectra are identical, while the Bose and Fermi eigenfunctions are related by $\psi^B=\psi^F A$ where $A(x_1\cdots x_n)$ is $+1$ or -1 according as the order $pq\cdots r$, when the x_j are arranged in the order $x_p<x_q<\cdots<x_r$, is an even or an odd permutation of $1\cdots n$. All configurational probability distributions of the two systems are identical, but the momentum distributions are quite different. The theory is illustrated by application to impenetrable point particles in a box with periodicity length L. Since for spinless fermions point interactions are equivalent to no interaction, one can find the rigorous energy spectrum and eigenstates of the corresponding Bose system. For odd n the ground state $\psi_0{}^B$ is $\pi_{j<l}|\sin[\pi L^{-1}(x_j-x_l)]|$; for even n it is twofold degenerate and slightly more complicated. The low excitations are phonons, the one-phonon states approaching the Feynman form $\psi_0{}^B\sum_j\exp(ikx_j)$ as $k\to 0$.

* Supported in part by U. S. Air Force Office of Scientific Research.

A11. Radiation Pressure at Relativistic Velocities. RICHARD SCHLEGEL, *Michigan State University*.—A field of electromagnetic waves is isotropic, with energy density u; a surface moves in the field with velocity v. Transformation of the wave amplitude factor leads to $u'=u(1-\beta^2)/(1-\beta\cos\phi')^2$, where u' is energy density in the rest system of the surface, ϕ' is the angle between surface normal and wave vector, and $\beta=v/c$. Integration of the radiation momentum reaching the forward-moving side of the surface gives for the radiation pressure P on this surface:

$$P=\frac{(1-\beta^2)u}{\beta^3}\left[\beta-1+2\log(1-\beta)+\frac{1}{1-\beta}\right].$$

For $\beta=0$, $P=u/3$; for $\beta\to 1$, B approaches the limit $2u$. With $\beta=1$, the integral of normally incident momentum over all ϕ' angles is properly defined and finite, in spite of the infinite momentum value at the single point $\phi'=0$. A consequence is that electromagnetic radiation pressure on a vehicle traveling at any speed in interstellar space would be negligible.

A12. Satellite Frequencies with a New Gravitational Potential.* JOHN P. VINTI, *National Bureau of Standards*.—A new gravitational potential,[1] expressed in oblate spheroidal coordinates ξ,η,ϕ, represents accurately the even-harmonic part of the earth's field and leads to quadrature solutions for satellite orbits. It therefore appears possible to find the orbital effects of oblateness without perturbation theory. If n_1,n_2,n_3 are the corresponding natural frequencies, then n_2 is the mean sidereal frequency, $1/n_2$ the mean time from ascending node to ascending node, and n_3-n_2 the mean secular rate of motion of the line of nodes in an inertial system. Whenever perigee is at a node, then $\xi=\xi_{\min}$, so that n_2-n_1 is the mean secular rate of the line of apsides relative to the line of nodes. Series expansions of these quantities in an oblateness parameter k show first-order vanishing of n_2-n_1 for a critical inclination 63.4°, with no singularities through second order. The perturbation theories (Brouwer, Garfinkel, private communications) reveal the same critical inclination, with singularities at that value. The absence of

singularities with the present potential is shown to arise from the special value of the fourth harmonic that it requires.

* Supported by the Air Force Office of Scientific Research.
[1] John P. Vinti, Phys. Rev. Letters **3**, 8 (1959).

A13. Electromagnetic Fields of a Charge and Anisotropic Medium in Relative Motion.* L. DIESENDRUCK, *University of Rhode Island.*—Using the Minkowski constitutive equations the electromagnetic potentials are obtained for the static problem of an isotropic medium in motion and charge at rest with respect to the observer. The elliptic equation for the suboptic case and the hyperbolic equation for the superoptic case are solved by the methods of Iwanenko and Sokolow[1] to give potentials which are generalizations of the Lienard-Wiechert potentials for vacuum. By means of the Lorentz transformation the potentials and fields are obtained for the medium at rest and the charge moving. Using the generalized constitutive equations for anisotropic media[2] the same procedure is followed to obtain the fields for the static case of charge at rest and medium moving and the case of medium at rest and charge moving. Illustrative examples will be presented.

* Supported by the National Science Foundation.
[1] D. Iwanenko and A. Sokolow, *Klassische Feldtheorie* (Akademie-Verlag, Berlin, 1933).
[2] L. Diesendruck, Bull. Am. Phys. Soc. Ser. II, **3**, 67 (1958).

WEDNESDAY MORNING AT 10:30

Statler-Hilton Gold Ballroom

(G. SCHARFF-GOLDHABER presiding)

Helicity; Radioactive Nuclei I

B1. Longitudinal Polarization of Electrons From Pr^{144}.* W. A. W. MEHLHOP,† E. D. LAMBE, AND T. A. POND, *Washington University.*—A Møller scattering apparatus[1] has been used for a precision comparison of the longitudinal polarizations of the Pr^{144}(2.98 Mev) and Y^{90}(2.24 Mev) beta particles with kinetic energies greater than 0.95 Mev. The scatterer was 2.56 mg/cm² Deltamax magnetized to about 14 500 G. Asymmetries under reversal of the magnetization, arising from geometric and electronic misalignments, were carefully studied and shown to be very small. Scatterings from chamber walls, and multiple scattering and depolarization in source and scatterer all resulted in small corrections: the ratio of Møller asymmetry under reversal of the magnetization for Pr^{144} to that for Y^{90} was shifted from 0.976 ± 0.026 (raw datum) to 0.986 ± 0.030 (corrected final value). The equality (within error) of these polarizations allows an upper limit to be set on the pseudoscalar interaction present in Pr^{144}. The limit set here is in agreement with that obtained from precision Pr^{144} spectrum-shape studies.[2]

* Supported by the U. S. Air Force Office of Scientific Research, the National Science Foundation, and the Research Corporation.
† Bell Telephone Laboratories Predoctoral Fellow; now at Brookhaven National Laboratory.
[1] Pond, Mehlhop, and Lambe, Bull. Am. Phys. Soc. Ser. II, **4**, 77 (1959).
[2] Graham, Geiger, and Eastwood, Can. J. Phys. **36**, 1084 (1958).

B2. γ Circular Polarization in Ar^{41} and Isotopic Spin Conservation.* STEWART D. BLOOM, LLOYD G. MANN, AND JOHN A. MISKEL, *University of California, Livermore.*—The Ar^{41} decay sequence $[\frac{7}{2}^-(\beta^-,1.25\text{ Mev})\frac{7}{2}^-(\gamma,M2,1.29\text{ Mev})\frac{3}{2}^+]$ offers the possibility of testing isotopic spin conservation by means of a circular polarization measurement of the γ ray emitted in coincidence with each β, since here it is only the $\Delta T=0$ law for allowed transitions which prohibits Fermi contributions to the transition. A polarization measurement has been made using a new method developed at this laboratory minimizing drift and gain-shift effects.[1] The result for the asymmetry parameter is $\alpha(Ar^{41})=0.07\pm0.07$. It is based on a comparison measurement of the same quantity in Co^{60}, whose decay scheme involves two gammas of average energy (1.25 Mev) close to the Ar^{41} gamma energy, making unnecessary a magnet polarization efficiency calculation—for the accuracy required here. The measured polarization in Ar^{41} corresponds to a value of $(4\pm10)\times10^{-2}$ for the ratio (M_F/M_{GT}). This number differs markedly from the values of ~0.30 to ~0.50 obtained for the same quantity in the case of Sc^{46},[2] which could indicate a considerable isotopic spin conservation breakdown in this atomic weight region.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] See abstract for this meeting by Mann, Bloom, Breshears, and Verdery.
[2] F. Boehm and A. H. Wapstra, Phys. Rev. **107**, 1202 (1957); R. M. Steffen, Phys. Rev. (to be published).

B3. Rapid-Alternation Method For Measuring Gamma-Ray Circular Polarization.* LLOYD G. MANN, STEWART D. BLOOM, J. D. BRESHEARS, AND D. VERDERY, *University of California, Livermore.*—Circular polarization is detected by means of Compton scattering from magnetized iron. For 100% polarization the counting rate changes by $\sim2\%$ when the direction of magnetization is reversed. Stability of the apparatus is therefore extremely important, especially when measuring only partially polarized gamma rays. The usual procedure, in coincidence experiments, has been to normalize the number of coincidences to the singles counts. We have designed a system which reverses the magnetic field direction every 6 sec, virtually eliminating drift effects. Two complete data storage systems (scalers) are provided, so that counts associated with different field directions are stored in separate scalers. In our coincidence experiments, total beta, gamma, coincidence, and time monitor counts are recorded. Timing is controlled from a 60-cy pulser. Due to the averaging effect of *many* periods, the individual periods need only be approximately equal in length; $\pm1\%$ would be adequate. Many runs of several hours have demonstrated that drift effects are smaller than our best statistical accuracy, $\sim0.01\%$.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

B4. v/c Dependence in Beta-Gamma (Circularly Polarized) Correlation.* Y. K. LEE, N. BENCZER-KOLLER, AND C. S. WU, *Columbia University.*—The v/c dependence of the β-γ (circularly polarized) correlation in Co^{60} was studied with a Gerholm type magnetic lens spectrometer set at 4% transmission and 6% resolution. A forward scattering cylindrical magnet was used as the circular polarization analyzer. About 250 μc of Co^{60} (187 μg/cm² thick) were deposited on a 20 μg/cm² Formvar film and covered by a 10 μg/cm² collodion film. The Kurie plot of the β spectrum which was taken in coincidence with the high energy end (350 to 630 kev) of the scattered γ spectrum exhibited linearity from the upper

energy end down to about 60 kev, below which it slightly deviated downwards, implying that electron scattering in the source or the spectrometer is negligible. At the following three electron energies, 42 kev ($v/c=0.40$), 122 kev ($v/c=0.60$), and 227 kev ($v/c=0.72$), the normalized ratio of the polarization to v/c was 1.14 ± 0.23, 1.00 ± 0.20, and 1.03 ± 0.21, respectively. The quoted errors include a 10% statistical error and the systematic errors. These results indicate that the circular polarization of γ rays in a β-γ cascade is directly proportional to the momentum of the preceding β particle in accordance with the two component neutrino theory.

* This work partially supported by the U. S. Atomic Energy Commission.

B5. Investigation of the Branching of Transitions in Some Mirror Nuclei.* W. L. TALBERT, JR.,† M. G. STEWART, AND D. J. ZAFFARANO, *Iowa State University.*—The possibility of branching in the decays of the mirror nuclides listed below has been investigated using NaI(Tl) scintillation detectors. The nuclear gamma rays emitted during the decays were detected in coincidence with the accompanying positron annihilation radiation. The results listed below were consistent with predictions of the presence of branching using the shell model and experimental data on configuration mixing. Upper limits were placed for branches in the cases where no gamma ray was identified in the decay, while for the cases where a gamma ray was present, the branching ratio was computed.

TABLE I.

Isotope	Half-life (sec)	Gamma-ray energies (Mev)	Branching ratio (%)
Na^{21}	23.0	0.347	2.2 ± 0.3
Mg^{23}	12.1	0.440	9.1 ± 0.5
Al^{26}	7.15	0.58, 0.98	<0.9
Si^{27}	4.14	0.842, 1.013	<0.2
S^{31}	2.72	1.267	1.1 ± 0.1
Ca^{39}	0.88	2.53	<0.6

* This work was supported by the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow, now at the Ohio Oil Company Research Center, Littleton, Colorado.

B6. Level Structure of Ca^{42} and Ca^{44}.* J. D. MCCULLEN AND J. J. KRAUSHAAR, *University of Colorado.*—Theoretical analyses of the level structure of nuclei in the calcium region have been hampered in the past by lack of detailed knowledge of the nature of the excited states of these isotopes. Preliminary work on the decays $K^{42} \rightarrow Ca^{42}$ and $Sc^{44} \rightarrow Ca^{44}$ carried out in this laboratory will be presented. The level structure of Ca^{42} is found to be in good agreement with the work of Morinaga *et al.*[1] An analysis of the gamma-ray singles spectrum of Sc^{44} shows lines with energies of 0.26 (metastable level in Sc^{44}), 1.15, 1.49, and 1.69 Mev, and the annihilation peak; corresponding intensities are found to be 82%, 100%, 1.7%, and 2.3%. Gamma rays in coincidence with the 1.16-Mev gamma ray are found at 1.16 and 1.49 Mev. The coincidence 1.16-Mev gamma ray accounts for about 4.6% of total 1.16-Mev intensity. Comparison of annihilation peak height with total population of the ground state of Sc^{44} indicates that 6% proceeds by K capture. Level schemes of the two isotopes and their significance will be discussed.

* Supported by U. S. Atomic Energy Commission.
[1] Morinaga, Mutsuro, and Sugarawa, Phys. Rev. 114, 1146 (1959).

B7. Higher-Order Effects in the Allowed, 1.5 Mev Positron Decay of Co^{58}. J. H. HAMILTON* AND B. G. PETTERSSON, *Uppsala University.*—The positron decay from the Co^{58} 4+ ground state to the Fe^{58} 4+ second excited state has an exceptionally high $\log ft=8.7$ for an allowed transition.[1] This is difficult to understand. More information about the decay to this Fe^{58} level should be useful in further analysis. The β-γ directional correlation of the 1.5 Mev positron group with both the 1.24 and 0.85 Mev gamma rays was measured as a function of beta energy from 0.7–1.2 Mev. The beta analyzer was a magnetic lens spectrometer. The correlation $A=[N(\pi)-N(\pi/2)]/N(\pi/2)$ varied from $(1.1\pm0.5)\%$ at 0.7 Mev to $(\simeq3.0+0.7)\%$ at 1.2 Mev. An isotropic β-γ dc with possible very small corrections is expected for allowed beta transitions. Only in the allowed Na^{22} decay has an anisotropy been reported[2] (-0.27%). The large anisotropy in Co^{58} should offer a better test of higher order effects in allowed beta decay. Theoretical analysis and a search for small effects in the beta spectrum are in progress.

* National Science Foundation Postdoctoral Fellow on leave from Vanderbilt University.
[1] P. Kienle and R. E. Segel, Phys. Rev. 114, 1554 (1959).
[2] R. M. Steffen, Phys. Rev. Letters 3, 277 (1959).

B8. Nuclear Levels of Ge^{74}. E. EICHLER, J. A. MARINSKY,* G. D. O'KELLEY, AND N. R. JOHNSON, *Oak Ridge National Laboratory.*†—The deexcitation of levels in Ge^{74} populated in the decay of Ga^{74} and As^{74} has been investigated by means of gamma- and beta-scintillation spectrometry. The single-crystal gamma-ray spectrum of Ga^{74} revealed the following gamma rays (and relative intensities): 0.5(−), 0.600(100), 0.70(2), 0.87(9), 0.96(4), 1.14(6), 1.20(9), 1.35(5), 1.46(7), 1.55(4), 1.74(3), 1.85(−), 1.95(4), 2.35(40), 2.50(3), 2.7(−), 2.95(4), and 3.2(3) Mev. These results are in good agreement with those of Ythier *et al.*[1] Gamma-gamma coincidence experiments have been performed gating on the 0.600, 0.87, 1.46, and 2.35 Mev gamma rays. The end point of the highest energy beta-ray group was observed to be at 2.7 Mev, and this same group was shown to be in coincidence with the 2.35-Mev gamma ray. These results indicate levels in Ge^{74} at 0.600, 1.20, 1.47 2.55, and 2.95 Mev. The angular correlation between the 0.60-0.60 Mev cascade in the decay of As^{74} has been studied.

* Permanent address: University of Buffalo, Buffalo, New York.
† Operated by the Union Carbide Nuclear Company for the U. S. Atomic Energy Commission.
[1] Ythier, Schoo, Schrom, Polak, Girgis, Ricci, and van Lieshout, Physica 25, 694 (1959).

WEDNESDAY MORNING AT 10:00

New Yorker Grand Ballroom

(MELVIN SCHWARTZ presiding)

Strange Particles

BA1. Photoproduction of K^+ Mesons from Deuterium.* F. TURKOT, W. M. WOODWARD, AND R. L. ANDERSON, *Cornell University.*—In order to obtain the differential cross section for the reaction $\gamma+n \rightarrow K^++\Sigma^-$, the ratio of the production of K^+ mesons in hydrogen and deuterium is being studied. The 1150 Mev bremsstrahlung beam is passed

through a liquid target, K^+ mesons produced at a laboratory angle of 25° and momentum 400 Mev/c are detected by means of a magnetic spectrometer. After traversing the spectrometer magnet, the K mesons pass through a counter telescope and are brought to rest in a 4-in.-thick aluminum block, which is surrounded on four sides by scintillation counters.[1] The criteria for a K meson are that it give the proper pulse height in three scintillation counters, that it not count in a Lucite Čerenkov counter, and that it give a decay pulse in at least one of the side counters surrounding the stopping block. Pions are rejected by the Čerenkov counter and by setting a lower limit to the pulse height requirement in the three scintillation counters. Protons have insufficient range to penetrate the telescope. Preliminary results indicate a yield from deuterium nearly twice that for hydrogen.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] McDaniel, Silverman, Wilson, and Cortellessa, Phys. Rev. 115, 1039 (1959).

BA2. K^- Meson by $\bar{p}$ Annihilation at 107 Bev/c.* T. F. Hoang, W. B. Fowler, F. Goldhaber, S. Goldhaber, W. M. Powell, and R. Silberberg, *Lawrence Radiation Laboratory, Berkeley.*—An investigation of K-meson production has been carried out using "hydrogen-like" $\bar{p}$-annihilation events observed in a 30-in. propane bubble chamber.[1] The K production is found to be $(8.4\pm1.3)\%$ and associated with 1.9 ± 1.1 charged π's. The average momentum in $\bar{p}$-p c.m. system is 333 Mev/c for K and 344 Mev/c for associated π; their spreads are 250 Mev/c and 230 Mev/c, respectively. The angles between pairs of $K\bar{K}$, $\pi\pi$, and $K\pi$ show a characteristic backward peaking with $BWD/FWD=2.8\pm1.5$, 2.5 ± 1.0, 1.2 ± 0.3, respectively. We have carried out statistical model calculations. The observed momenta of K and π mesons are consistent with those calculated from covariant phase space. The increase in K-production at our energy compared to $4.0\pm1.2\%$ observed at low energy[2] is reasonable on the basis of phase space considerations. By comparing 5π and $2K3\pi$ annihilations, we deduce that $\Omega_K/\Omega_\pi\sim0.5$.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Preliminary results reported by S. Goldhaber *et al.*, Bull. Am. Phys. Soc. Ser. II, **4**, 368 (1959).
[2] L. E. Agnew, UCRL-8785 (thesis).

BA3. Collisional De-Excitation of (K^-,p) Atoms in Hydrogen.* J. E. Russell and Gordon L. Shaw, *Indiana University.*—We considered the de-excitation of (K^-,p) atoms in a hydrogen bubble chamber. For $5\lesssim n\lesssim15$ radiative and molecular effects are relatively unimportant, and de-excitation occurs by (a) ejection of an electron from a nearby hydrogen atom,[1] or (b) transfer of energy from the (K^-,p) atom to energy of relative motion between the mesonic atom and a hydrogen atom. Cross sections for processes (a) and (b) were computed in Born approximation and were found to be comparable. Although the Born approximation greatly overestimates both these cross sections, the ratio σ_a/σ_b may be meaningful. If (b) is important, the mesonic atom will, after each such process, acquire a recoil velocity much greater than the thermal velocities of the hydrogen atoms. If the recoiling (K^-,p) atom is not slowed down too rapidly by elastic collisions, the much smaller wavelength associated with these large velocities would bolster considerably the semiclassical arguments[2] concerning the Stark effect reshuffling and subsequent S state absorption of K^- mesons.

* Supported by the National Science Foundation.
[1] A semiclassical calculation of (a) by A. S. Wightman (Ph.D. thesis, Princeton, 1949) indicated that de-excitation would be rapid.
[2] Day, Snow, and Sucher, Phys. Rev. Letters 3, 61 (1959).

BA4. Branching Ratios in the Mesic Decay Modes of $_\Lambda H^3$ and $_\Lambda H^4$. R. Ammar, R. Levi Setti, and W. E. Slater,* *The University of Chicago,* and S. Limentani, P. E. Schlein, and P. H. Steinberg,† *Northwestern University.*—The relative frequencies, R_3 and R_4, for the decay modes $_\Lambda H^3\rightarrow\pi^-+He^3$ and $_\Lambda H^4\rightarrow\pi^-+He^4$ relative to the total number of $_\Lambda H^3$ and $_\Lambda H^4$ mesic decays, respectively, will be presented. Preliminary results were reported elsewhere.[1] Unbiased data will be available on a total of about 110 $_\Lambda H$ events, having hyperfragment ranges >20 μ. Possible biases may arise from (a) different detection efficiencies for the various decay configurations, (b) escape from stack or interaction of the decay pions, and (c) events of ambiguous identification. These are taken into account by (a) determining the relative efficiencies for various decay modes evaluated from coincidences in repeated scannings, (b) determining the incomplete pion residual range from blob count, and (c) measuring Z and A of the primary track as well as using the known binding energies of $_\Lambda H^3$ and $_\Lambda H^4$ as a discrimination factor.

* Research supported by the U. S. Air Force Office of Scientific Research.
† Research supported by the National Science Foundation and by the U. S. Atomic Energy Commission through Argonne National Laboratory.
[1] Same authors, reported by R. H. Dalitz at the Kiev conference on High Energy Physics (1959).

BA5. Decay Asymmetry of Σ^+ and Λ^0 Hyperons.* James W. Cronin,† *Princeton University and University of California, Berkeley,* Bruce Cork, Leroy Kerth, William A. Wenzel, *University of California,* and R. L. Cool, *Brookhaven National Laboratory and University of California, Berkeley.*—Counter techniques have been used to measure decay asymmetries for polarized Λ^0 and Σ^+ hyperons. The Σ^+ hyperons were produced by 1.13 Bev/c π^+ in the reaction $\pi^++p\rightarrow\Sigma^++K^+$. The Λ^0 hyperons were produced by 1.00 Bev/c π^+ in the reaction of $\pi^++d\rightarrow K^++\Lambda^0+p$. The asymmetry for each hyperon decay mode was measured by a counter arrangement which detected separately charged pions and γ rays from π^0's. The protons from the hyperon decay were also detected to confirm the identification of decay modes. We have measured the product $\alpha\bar{P}$, where α is the asymmetry parameter and $\bar{P}$ is the average polarization of the hyperon. The data give the following preliminary results for the various decay modes:

$$\Sigma^+\rightarrow\pi^++n \qquad \alpha\bar{P}=+0.02\pm0.08$$
$$\Sigma^+\rightarrow\pi^0+p \qquad \alpha\bar{P}=+0.62\pm0.12$$
$$\Lambda^0\rightarrow\pi^-+p \qquad \alpha\bar{P}=+0.46\pm0.04$$
$$\Lambda^0\rightarrow\pi^0+n \qquad \alpha\bar{P}=+0.56\pm0.10$$

The quoted errors are due to counting statistics only; some possible systematic errors remain to be investigated. The results for the Σ^+ decay modes confirm with improved accuracy an earlier experiment.[1] The ratio $\alpha(\Lambda^0\rightarrow\pi^0+n)/\alpha(\Lambda^0\rightarrow\pi^-+p)=+1.22\pm0.24$ is in agreement with the value $+1.00$ predicted by the $|\Delta I|=\frac{1}{2}$ rule for hyperon decay.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Cool, Cork, Cronin, and Wenzel, Phys. Rev. 114, 912 (1959).

BA6. Hyperfragment Production in the Helium Bubble Chamber. E. M. Harth and J. Leitner, *Syracuse University,* R. Gessaroli, A. Minguzzi-Ranzi, and G. Puppi, *Bologna, Italy,* M. M. Block, E. B. Brucker, C. C. Chang, T. Kikuchi, and C. Meltzer, *Duke University,* A. Pevsner and P. Schlein, *Johns Hopkins University,* and H. O. Cohn, *Oak Ridge National Laboratory.*—The Duke helium bubble chamber has been exposed to a low momentum separated K^- beam at the Bevatron. In reactions in which the K^- was absorbed at rest, $_\Lambda H^3$, $_\Lambda H^4$, and $_\Lambda He^4$ hypernuclei have been identified from the production channels $K^-+He^4\rightarrow\pi^-+p+{}_\Lambda H^3$, $\pi^0+{}_\Lambda H^4$, $\pi^-+{}_\Lambda He^4$. To date, 20 hypernuclei have been found among about 1500 K^- stops. The following decay modes have been observed; $_\Lambda H^3\rightarrow p+d+\pi^-$ and $p+p+n+\pi^-$; $_\Lambda H^4\rightarrow He^4+\pi^-$ and H^3+n; $_\Lambda He^4\rightarrow\pi^-+p+He^3$, $d+d$, He^3+n and π^0+He^4

Preliminary estimates of frequency of production, branching ratios, and lifetimes of the hyperfragments will be reported.

BA7. Identification of Hypernuclei $\geq {}_{\Lambda}Li$ by K^- Absorption Analysis in Nuclear Emulsion. P. E. SCHLEIN* AND W. E. SLATER,† *University of Chicago.*—Analysis of the production reactions, (K^-,Σ^-)+emulsion nucleus → hypernucleus+residual particles, will often provide additional information for the identification of the heavier hypernuclei. To our knowledge, only two isolated examples of such analysis exist in the literature. In the work reported here the EFINS events from EFINS-NU collaboration[1] were studied in order to investigate the extent to which production analysis would be generally useful in resolving certain hypernucleus-identification ambiguities. To be reported are (1) 3 examples of mesic ${}_{\Lambda}C^{12,13}$. One of these is a unique example of ${}_{\Lambda}C^{13}$ which probably decays into $N^{13}+\pi^-$ with $B_{\Lambda}=10.8\pm0.6$ Mev. (2) One new example of mesic ${}_{\Lambda}B^{12}$ with $B_{\Lambda}=9.9\pm0.6$ Mev, production analysis of the ${}_{\Lambda}B^{11}$ event presented in reference 1, and an example of nonmesic ${}_{\Lambda}B^{12}$. (3) One example of ${}_{\Lambda}Be^{8,9}$ whose Λ^0 is produced in a two-nucleon primary reaction $K^-+2H^1 \rightarrow \Lambda^0+H^1+317$ Mev. This hypernucleus is most probably produced in C^{12}. (4) Production analyses of other heavy hypernuclei some of which have a bearing on the existence of Be^{10}. All heavy hypernuclei thus far analyzed have been produced in C^{12} or O^{16}.

* Now at John Hopkins University.
† Now at University of California, Los Angeles.
[1] Ammar, Levi-Setti, Limentani, Schlein, Slater, and Steinberg, Nuovo cimento (to be published).

BA8. Search for Hyperfragments Simulating Σ^- Capture.* O. SKJEGGESTAD, R. AMMAR, R. LEVI SETTI, J. E. MOTT, P. E. SCHLEIN, AND P. K. SHRIVASTAVA, *The University of Chicago.*—A systematic research has been undertaken to discover whether among particles emitted from K^- capture in nuclear emulsion, there are particles more massive than Σ^- which simulate the appearance of a Σ^- star. Only those events with connecting tracts ≥ 1 mm and dip angles $\leq 30°$ will be discussed; prongs from K^- capture are traced through the stack in order to include those events not contained in a single pellicle (1200-μ thick *K*5 emulsion). Particle masses are determined from gap-length *vs* range measurements, carried out on microscopes equipped with mechanized stages. Results of measurements on $\gtrsim 50$ events will be reported both with a view towards the detection of a possible $(\Sigma^-\eta)$ compound (1) as well as nonmesic decays of ${}_{\Lambda}H$. To date one example of the latter type of event has been identified.

* Research supported by the U. S. Air Force Office of Scientific Research.
[1] Gandolfi, Heughebaert, and Quercigh, Nuovo cimento 8, 864 (1959).

BA9. Search for the Strangeness 2 Meson.* JAY OREAR, *Cornell University.*—T. Yamanouchi[1] has recently suggested that the two anomalous *K* meson decays found by the Columbia[2] and Bristol[3] groups may actually have been two-body decays $D^+ \rightarrow \pi^+ + K^0$ rather than $K^+ \rightarrow \pi^+ + \pi^0 + \gamma$. In both events the π^+ energy was 60 Mev. In the suggested two-body decay mode the primary mass would be 719 ± 2 Mev. If the primary mass is 719 Mev rather than 494 Mev the primary grain count would be 13% higher than that of a *K* meson at 2 cm residual range. The primary of the Columbia event has now been grain counted with the result 48.5 ± 0.8 grains/100 μ normalized to a 2-cm residual range. A comparison *K* in nearby plates has a count of 60.6 ± 0.8 grains/100 μ at 2-cm residual range. The conclusion is that the Columbia particle cannot possibly be the particle suggested by Yamanouchi.

* Research supported by the National Science Foundation.
[1] T. Yamanouchi, "On the strangeness 2 meson" (submitted to Phys. Rev. Letters).
[2] Harris, Lee, Orear, and Taylor, Phys. Rev. 108, 1561 (1957).
[3] Prowse and Evans, Nuovo cimento 8, 856 (1958).

WEDNESDAY MORNING AT 9:45

Statler-Hilton Skytop Room

(K. R. ATKINS presiding)

Cryogenics

C1. Dielectric Breakdown in Liquid He^4. M. H. EDWARDS, *Royal Military College,* AND C. BLANK, *University of Pennsylvania.*—The dielectric strength of liquid He^4 under its saturated vapor pressure has been determined from 1.2 to 4.2°K. With $\frac{3}{4}$ in. diam spherical steel electrodes 0.15 mm apart the average breakdown field, E_b, is approximately 1 Mv/cm, nearly independent of temperature. At spacings of 1 mm E_b is lower, but increases with increasing temperature, being about 0.25 Mv/cm at 2°K. The mechanism of breakdown is not clear, but field emission of electrons from the cathode is probably involved, because the breakdown potential V_b, obtained with a negative point and a positive plane electrode is about half that obtained with a positive point and a negative plane. Pre-breakdown currents, if they exist, are probably less than 10^{-13} A.

C2. Velocity of Sound in Liquid He^3 at High Pressures.* H. FLICKER† AND K. R. ATKINS, *University of Pennsylvania.*—The velocity of 14 Mc/sec sound in liquid He^3 was measured at pressures up to 9 atmos in the temperature range 1.2 to 3.2°K. A few measurements were also made in the gas just above the critical temperature. A possible phonon contribution to the thermal coefficient of expansion of the liquid is discussed.

* Supported by the National Science Foundation.
† Union Carbide Fellow. Now with RCA Laboratories, Princeton.

C3. Dispersion Curve in Liquid Helium by Inelastic Scattering of Neutrons. D. G. HENSHAW, A. D. B. WOODS, AND B. N. BROCKHOUSE, *Chalk River Laboratories.*—The change in wavelength of 4.05 A neutrons scattered from 5 in. diam specimens of liquid helium at 1.1$_5$°K has been measured at 21 angles of scattering in the angular range 10° to 140.7° using a new high-resolution double crystal spectrometer at the Chalk River N.R.U. reactor. At these temperatures, the neutrons scattered with the production of a single excitation quantum shows a discrete change in energy (ΔE) with little broadening even at large momentum change ($\hbar Q$). Representative values of $Q(A^{-1})$ and $\Delta E(°K)$ are

(0.27 A^{-1}, 5.2°K)	(1.47$_0$ A^{-1}, 12.3°K)	(2.26$_9$ A^{-1}, 13.2°K)
(0.59 A^{-1}, 10.5°K)	(1.93$_8$ A^{-1}, 8.66°K)	(2.48$_8$ A^{-1}, 15.9°K)
(1.12$_8$ A^{-1}, 13.7°K)	(2.06$_2$ A^{-1}, 9.55°K)	(2.68 A^{-1}, 17.1°K).

For $Q \leq 0.6$ A^{-1}, the curve may be fitted by a phonon branch $\hbar Qc$ (c is the velocity of sound (237 m/sec^{-1}). For 0.6 $A^{-1} \leq Q$

$\leq 2.3\ A^{-1}$, the measurements are consistent with Yarnell *et al.*[1] For $Q=2.25\ A^{-1}$ the slope $\simeq c$. Above $2.25\ A^{-1}$ the curve has a negative second derivative suggesting the possible existence of a theoretically unpredicted second maximum. At the largest value of Q ($2.68\ A^{-1}$), the cross section for production of a single quantum is only $\sim 6\%$ of the cross section at the minimum ($Q=1.91\ A^{-1}$).

[1] Yarnell, Arnold, Bendt, and Kerr, Phys. Rev. **113**, 1379 (1955).

C4. Thermal Conduction in Rotating Liquid Helium II.* C. E. CHASE, *Lincoln Laboratory.*—Vinen[1] has shown that in wide (~ 1 mm) channels the relation between temperature gradient and heat current density is $\text{grad}T=D(W-W_0)^3$, and that establishment of this gradient requires a time τ, which is a function of heat current, temperature, and past history of the helium. These results were explained on the assumption that mutual friction results from turbulence in the superfluid, this turbulence taking the form of a tangled mass of vortex line. The present experiments concern the effect of uniform slow rotation, about an axis normal to the direction of heat flow, on $\text{grad}T$ and τ. No change in $\text{grad}T$ was observed, but an appreciable reduction in τ occurred. If it is assumed that rotation produces an array of vortex lines parallel to the axis of rotation, these results can be qualitatively explained in terms of Vinen's theory of the growth of mutual friction in a heat current. An additional transient decrease in τ during the first few seconds of rotation can be attributed to turbulent acceleration of the liquid.

* The work reported in this paper was performed by Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology with the joint support of the U. S. Army, Navy, and Air Force.
[1] W. F. Vinen, Proc. Roy. Soc. (London) **A240**, 114 (1957); **A240**, 128 (1957); **A242**, 493 (1957).

C5. Thermal Resistivity of Isotopic Mixtures of Solid Helium.* EDWARD J. WALKER AND HENRY A. FAIRBANK, *Yale University.*—The thermal resistivity of solid He^4 containing zero, 0.56, 1.38, and 2.8% He^3 has been measured as a function of temperature from 1.1 to 2.1°K. For pure He^4, the results are in satisfactory agreement with those of Webb, Wilkinson, and Wilks.[1] The addition of 1.38% He^3, at a sample density $\rho=0.208\ g/cm^{-3}$ caused an increase in thermal resistivity by a factor of 5 at 1.1°K. The additional thermal resistance caused by adding He^3 was substantially independent of temperature, rather than proportional to temperature, as would be expected from isotropically distributed point scatterers. From this fact and from the magnitude of the isotope resistance it is inferred, using Klemens theory,[2] that the He^3 is arranged on lines in the solid. Possible mechanisms to explain these results are discussed.

* Assisted by the Office of Naval Research.
[1] Webb, Wilkinson, and Wilks, Proc. Roy. Soc. (London) **A214**, 546 (1952).
[2] P. G. Klemens, Proc. Roy. Soc. (London) **A68**, 1113 (1955).

C6. Moment of Inertia of Superfluid Many-Fermion Systems.* RONALD M. ROCKMORE, *Brookhaven National Laboratory.*—The effects of possible superfluidity on the cranking moment of a many-fermion system moving under periodic boundary conditions are considered. The Hamiltonian which includes the cranking terms is initially subjected to Bogolyubov's general unitary transformation with the collective excitations of the fermions described by the usual pair approximation. A unitary transformation of the excitation Hamiltonian then yields a stationary expression for the moment of inertia, which contains both the effects of possible superfluidity and collective excitation. In the normal case, the moment is found to have the rigid value. In the superfluid case, the moment exhibits a resonant behavior due to collective excitation although its value is still quite small compared to the rigid value. The role played by particle-pairs, hole-pairs, and particle-hole pairs in the two cases will be discussed. Variational expressions for the moment for Yukawa and delta-function potentials will be given. A calculation of the cranking moment at finite temperatures will be presented together with its interpretation in terms of Bardeen's two-fluid model of superconductivity.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

C7. Transport Properties of Superconductors. LEO P. KADANOFF* AND P. C. MARTIN,† *Harvard University.*—The transport properties of a system describe the flow of densities of conserved quantities when the system is perturbed from equilibrium. These properties may be discussed in terms of frequency and wave-number dependent transport coefficients, which are Fourier transforms of correlation functions of the conserved currents. The transport coefficients, together with the conservation laws, determine the hydrodynamical relaxation of deviations from equilibrium. The familiar transport coefficients of a degenerate Fermi gas may be obtained using a simple approximation for the two particle Green's function in which the finite lifetime of the single particle excitation is retained. Identical techniques may be employed with a superconductor. Using Green's functions which account for the binding of particles with opposite spin, we have evaluated the transport coefficients of pure superconductors. The thermal conductivity exhibits a marked decrease in the neighborhood of the critical temperature. The sound wave and collective modes obtained at frequencies smaller than the inverse lifetime are significantly different from results derived using infinite lifetimes. Since the entire procedure preserves particles conservation, there are no difficulties with gauge invariance.

* National Science Foundation Predoctoral Fellow.
† Supported in part by the U. S. Air Force Office of Scientific Research.

C8. Intermediate State in Cylindrical Superconductors.* C. A. SHIFFMAN, *National Bureau of Standards.*—The field variation along the axis of long circular cylinders of superconductors has been measured in the presence of a transverse magnetic field of sufficient magnitude to place the specimen in the intermediate state. A bismuth micro-probe technique[1] is used to sense the field variations and hence, the normal and superconducting domain distributions. Adequate resolution is guaranteed by the use of probes with effective dimensions of about 20 μ, scanning the specimen surface at a separation of less than 20 μ. The domain distribution has been measured as a function of specimen size, metallurgical state, magnetic field, and temperature mainly in the case of tin, but to some extent for aluminum. The results are discussed in terms of the various models of the intermediate state and the theories of the surface energy between normal and superconducting phases.

* Research supported by the U. S. Air Force Office of Scientific Research.
[1] Meshkovsky and Shalnikov, J. Phys. U.S.S.R. **11**, 1 (1947).

C9. Superconductivity of Dilute Indium-Mercury Alloys.* MORTON D. REEBER, *I. B. M. Research Laboratory* (introduced by W. B. Ittner III).—Measurements were made of the critical magnetic field for the transition from the superconducting to the normal state in polycrystalline rods of the substitutional solid solution In-Hg, containing 0–7 at. % Hg. The treatment given these alloys was designed to assure homogeneity in composition in which case the transitions to the normal state were found to be similar to those for pure elemental superconductors. It was, moreover, possible to distinguish between properties that are characteristic of the ideal alloy system and properties which arise from structure within the specimen. The transition temperature in zero field was measured as a function of composition, and was found initially to decrease (up to a concentration of 1.75 at. % Hg) after which it began to increase with added Hg concentration.

The width of the transition to the normal state, as measured by the variation of specimen resistance in a longitudinal magnetic field, was found to show a regular dependence upon composition, and also reached a minimum value at 1.75 at. % Hg. The superconducting properties of pure indium were measured and used as a standard.

* Supported in part by the U. S. Department of Defense.

C10. Critical Fields of Thin Superconducting Tin Films.* W. B. ITTNER III AND R. H. BLUMBERG, *I. B. M. Research Laboratory.*—Tin films of thickness ranging from 500 A to 150 000 A have been fabricated in a manner designed to produce as nearly as possible a geometry corresponding to an "idealized" thin film. Measurements have indicated that the critical magnetic fields of such films can be described by an equation of the type derived by London[1] only if a penetration depth considerably greater than the bulk value of approximately 510 A is assumed. Consequently, calculations of the magnetic field penetration in a thin film were carried out for the non-local theories of Pippard and Bardeen using the equations obtained by Schrieffer.[2] It was found that an effective penetration depth, which could be defined through a comparison of the local theory of London to the non-local theories, could be used to describe with reasonable accuracy the observed critical fields of the measured films.

* Supported, in part, by the U. S. the Department of Defense.
[1] F. London, *Superfluids* (John Wiley & Sons, Inc., New York, 1950), Vol. 1, p. 130.
[2] J. R. Schrieffer, Phys. Rev. **106**, 47 (1957).

C11. Thermal Conductivity of Indium and Indium-Mercury Alloys at Liquid Helium Temperatures.* A. M. TOXEN AND R. E. JONES, *International Business Machines Corporation.*—The thermal conductivities of a high purity indium specimen (99.999%) and two alloy specimens, containing 0.50 and 0.98 at. % Hg respectively, have been measured over the temperature range 1.4 to 4.2°K. All of the specimens are polycrystalline and have sharp superconducting transitions, the interval of field over which the transitions occurred being less than 0.005 H_c.[1] An expression of the form $W=A/T+BT^2$ accurately represents the normal resistivity of the indium specimen which implies electronic conductivity limited by phonons and static imperfections. The quantity A is approximately 0.029°K[2] cm/w indicating a residual electrical resistivity ρ_0, of about 0.00071 $\mu\Omega$ cm and a resistivity ratio, $\rho_{298°}/\rho_0$, of 12 000, while B was measured to be 1.19×10^{-3} cm/°K w. In the alloy specimens, the resistivity went inversely with temperature indicating electronic conductivity with static imperfections the dominant scatterers. The decrease of conductivity of these specimens on entering the superconducting state will be discussed.

* Work supported in part by the Department of Defense.
[1] M. D. Reeber, "Superconductivity of dilute indium-mercury alloys" (submitted to *The Physical Review*).

C12. Ultrasonic Attenuation and Dispersion in Metals at Low Temperatures. A. B. BHATIA AND R. A. MOORE, *University of Alberta.*—When a sound wave passes through a metal, an electric field is set up in the metal. This electric field exerts a force on the ions. In addition, ions experience a force due to the transfer of momentum to the ions in electron-ion collisions. Because of the finite relaxation time τ for the electrons, the resultant of these two forces is out of phase with the displacements of the ions, and hence leads to the attenuation and dispersion of sound. The present approach, which seems to be somewhat more physical, gives substantially the same results as obtained by Pippard and Steinberg by other methods. The significance of the relaxation time τ will also be discussed. In particular, it is found that when the sound wavelength is large compared with the mean free path of the electrons, τ may be written as $(\tau)^{-1}=a(\tau_e)^{-1}+(\tau_e)^{-1}$. Here, a is of the order of magnitude unity, τ_e is the relaxation time for the electrical conductivity, and τ_e is a relaxation time describing the inter-electronic collisions. Thus, where electron-electron collisions are not unimportant, information regarding their relaxation time τ_e may be deduced from the measurements of attenuation and electrical conductivity.

WEDNESDAY MORNING AT 10:00

New Yorker Panel Room

(YARDLEY BEERS presiding)

Optical Physics; General Physics I

CA1. Hyperfine Structure of Atomic Nitrogen.* S. M. BLINDER, *Applied Physics Laboratory, Johns Hopkins University.*—The hyperfine structure of ^4S atomic nitrogen arises from exchange polarization of the 1s and 2s shells by the three unpaired 2p-electrons. The problem is treated within the formalism of the unrestricted Hartree-Fock method.[1] The radial equations for the $1s\beta$ and $2s\beta$ orbitals contain no terms corresponding to exchange with $2p\alpha$ orbitals. These are regarded as unperturbed systems with wave functions as computed by Hartree.[2] Exchange interaction with the $2p\alpha$ orbitals is treated formally as a perturbation of the $1s\alpha$ and $2s\alpha$ Hamiltonians. Accordingly, $2s\alpha$ character becomes admixed into the $1s\alpha$ orbital and vice versa. Exchange increases the $1s\alpha$ density but decreases the $2s\alpha$ density at the nucleus. These contributions very nearly cancel, but the 1s predominates slightly. The hyperfine coupling constant is thus negative. Mutual perturbation by the 1s and 2s orbitals accounts for a strong field hyperfine splitting of 10.07 mc/sec in N^{14} (experimental value: 10.45 mc/sec).[3] Contributions from higher s states are shown to be relatively unimportant as regards hyperfine structure.

* Work supported by Bureau of Ordnance, Department of the Navy.
[1] R. K. Nesbet, Proc. Roy. Soc. (London) **A230**, 312 (1955).
[2] D. R. Hartree and W. Hartree, Proc. Roy. Soc. (London) **A193**, 299 (1948).
[3] M. A. Heald and R. Beringer, Phys. Rev. **96**, 645 (1954).

CA2. Isotope Shift in Silicon Spectrum. JOHN R. HOLMES AND MARTIN E. HOOVER, *University of Southern California.*—The isotope shift in several lines of the spectrum of atomic silicon has been observed, using a Fabry-Perot interferometer. A sample of elemental silicon enriched to 72.5% in Si^{30} was excited in a hollow cathode discharge tube cooled in liquid nitrogen. Neon was used as a carrier gas. Preliminary results indicate that the shift in the $\lambda-2435(3p'D_2-3d'D_2^0)$ line is considerably larger than in some transitions involving S electrons. Experimental values will be presented.

CA3. Calculations for the First Spectrum of Thorium (Th I). R. E. TREES, *National Bureau of Standards.*—The analysis of Th I has recently been extended,[1] and in the $6d^37s$ and $6d^27s^2$ configurations twenty-one of a possible forty-seven levels have been identified. A calculation with seven free parameters leads to a mean error of ± 143 cm^{-1}. This is comparable with mean errors of ± 184 cm^{-1} and ± 137 cm^{-1} obtained in calculations for Th III[2] and Th II[3] respectively. The mean error for Th I is reduced to ± 47 cm^{-1} by use of eleven free parameters. The calculations were carried out on the IBM 704 by utilizing a code that has been written recently. Features of the code allow considerable flexibility and convenience in using it. The calculations in Th I will be used to illustrate difficulties that were encountered, some of which indicated a need for amplification of the code.

[1] R. Zalubas, J. Research Natl. Bur. Standards U. S. **63A**, 275 (1959).
[2] G. Racah, Physica **16**, 651 (1950).
[3] Y. Eisenberg, Physica **18**, 177 (1952).

CA4. Method for the Absolute Determination of Internal Conversion Coefficients and Photoelectric Cross Sections. S. HULTBERG* AND R. STOCKENDAL, *Nobel Institute of Physics, Stockholm.*—The new method[1,2] consists of the comparison of conversion lines and photolines measured under identical conditions. The internal conversion coefficient is proportional to the photoelectric cross section through a simple formula which involves the thickness of the photoelectric converter and a correction factor which accounts for the anisotropy of the photoelectric emission. The correction factor is given by the ratio between two simple integrals[1,2] and depends on six parameters which describe the experimental setup in the spectrometer. To carry out the integrations requires knowledge about the differential photoelectric cross sections. Such cross sections have been measured experimentally[3] and reported in numerical form[2] for three energies. The complete calculation of the correction factor has been programmed for the Swedish electronic computer BESK and service is offered whereby such calculations can be undertaken on request (directed to Nobel Institute of Physics, cf. reference 3).

* Present address: Vanderbilt University.
[1] S. Hultberg and R. Stockendal, Arkiv Fysik **14**, 565 (1959).
[2] S. Hultberg, Arkiv Fysik **15**, 307 (1959).
[3] S. Hultberg and Z. Sujkowski, Phys. Rev. Letters **3**, 227 (1959).

CA5. Infrared Quantum Converter. W. A. ROBINSON, *Space Technology Laboratories, Inc.*—A method of converting infrared quanta into quanta of visible or ultraviolet wavelengths which makes use of the Raman effect will be described. The intensity of an anti-Stokes Raman line is a measure of the population of the excited state corresponding to that Raman transition. If infrared radiation of wavelength corresponding to an absorption line is shown onto a material, the population of the excited state may be increased. If this absorption line is also Raman active, the intensity of the anti-Stokes line will be increased. The efficiency of such a converter depends mostly upon the chance that an excited state will decay by thermal interactions before a Raman transition can take place. Spontaneous transitions are probably unimportant since most of such radiation will be recaptured.

CA6. Charge Equilibria and Charge Changing Collision Cross Sections for Lithium Ionic and Atomic Beams. S. K. ALLISON, J. CUEVAS, M. HUBERMAN, AND M. GARCIA-MUÑOZ, *University of Chicago.*—Li^+ ionic beams, accelerated to kinetic energies in the range 10–450 kev, have been brought to charge equilibrium through traversal of various gases. The charge components have been magnetically analyzed as measured as fractions of the total beam if they appear in excess of 1 part in 10^5. Li^-, Li^0, Li^+, Li^{++}, and Li^{+++} have been measured in beams emergent from H_2, He, and N_2 gases. At the lower part of the energy range C_2H_2 and N_2O were also used; here they produced relatively large Li^- fractions, but this exceptional behavior did not persist to higher energies. In N_2, the maximum Li^- beam fraction occurs at $\sim$150 kev, and is 2.3×10^{-4}. In comparison to the yield from other gases, there is an exceptionally large output of Li^{++} from He gas in the energy range below 200 kev. The total charge changing collision cross sections for the four ionic beams and the atomic beam have been measured. By combining our data with other data on H and He beams, we can study the behavior of the iso-electronic structures H^+, He^{++}, Li^{+++} and H, He^+, Li^{++} in the same gas at the same velocity. In this way, for instance, the resonant nature of the capture cross section of He^+ in He gas is clearly demonstrated.

CA7. Collision Processes in Mixtures of Mercury Vapor and Foreign Gases. DONALD E. CUNNINGHAM* AND LEONARD O. OLSEN, *Case Institute of Technology.*—An extensive and quantitiative study of collision processes occuring in mercury vapor-foreign gas mixtures has been performed. Measurement of the polarization of mercury resonance radiation allows a determination of the probability for quenching, adiabatic depolarizing, and nonadiabatic depolarizing collisions. The use of a photomultiplier circuit in securing the data, and of an IBM 610 computer in analysis of the data, made the breadth of this study possible. The most important result is that no adiabatic depolarization is needed to account for the results obtained for all foreign gases studied. All quenching and depolarizing probabilities obtained in this study, and by earlier experimenter,[1–3] are summarized in tabular form.

* Now at American Institute of Physics.
[1] Ellett, Olsen, and Petersen, Phys. Rev. **60**, 107 (1941).
[2] L. Olsen, Phys. Rev. **60**, 739 (1941).
[3] L. Olsen and G. P. Kerr, Jr., Phys. Rev. **72**, 115 (1947).

CA8. Survey of Electron Impact Studies of Argon Done in Several Laboratories. M. A. FINEMAN AND R. BOUFFARD, *Providence College* and National Bureau of Standards.*—With a Lozier electron impact apparatus, ionization efficiency curves for argon were obtained using essentially monoenergetic electrons. In addition to breaks in the curves corresponding to the formation of $Ar^+(^2P_{\frac{3}{2}})$ and $Ar^+(^2P_{\frac{1}{2}})$, a third break was noted about 1.0 ± 0.2 v above the first ionization potential. The literature contains no reports of an ionization process in argon around 16.7 ev. As we had confidence in our electron impact data, we notified others, who do electron impact work with essentially monoenergetic electrons, of our unexpected results. Several replied that they too observed a similar break and kindly forwarded us much of their own data. A summary of the several sets of data on argon will be presented. A brief discussion as to the reliability of the existence of a new break in the ionization efficiency curves of argon will then follow. Speculations as to an explanation for the new break will be made. Finally, some conclusions will be given as to the significance of the results of this survey.

* Work performed at Providence College supported in part by the U. S. Atomic Energy Commission.

CA9. Ionization Yield of Low-Energy Heavy Ions in Argon.* J. A. PHIPPS, L. C. TOWLE, AND R. A. LOWRY, *University of Virginia.*—A cylindrical ionization chamber with a differentially pumped open window has been used to measure the total ionization yield of low energy heavy ions stopped in a gas. The ionization yield of protons in argon in the energy range of 25 to 250 kev was determined earlier.[1] Recent results will be presented on the ionization yield of argon and nitrogen ions in argon gas in the energy range of 25 to 100 kev. The average energy per ion pair for argon ions increases rapidly with decreasing energy in the above range and at 50 kev it is about three times the value for 200-kev protons. A comparison

of the ionization yields in argon of various ions having velocities in the same region will be presented.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] R. A. Lowry and G. H. Miller, Phys. Rev. **109**, 826 (1958).

CA10. Secondary Positive Ion Emission from Copper.* E. RUEDL AND R. C. BRADLEY, *Cornell University.*—Secondary positive ions ejected from single crystal copper surfaces under the action of inert gas ion bombardment have been analyzed in a high vacuum mass spectrometer using techniques previously described.[1] Principal ion species were Cu^+ and CuO^+ (although both were absent after prolonged heating at 650°C), Na^+ and K^+ impurities, and "reflected" ions of the primary beam (e.g., Xe^+ or A^+). Cu_2^+ and Cu_2O^+ peaks were also observed, but at a level 100 times lower than the Cu^+ and CuO^+ peaks. The Cu^+ and CuO^+ peaks seemed interdependent in that they were either both present or both absent. However, their dependences on bombardment parameters were very different. Activation energies for the volume diffusion of K^+ and Na^+ were measured and found to be 2.3 ± 0.1 and 2.5 ± 0.1 ev, respectively. The description energy of K^+ was 1.2 ± 0.1 ev.

* This research was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
[1] R. C. Bradley, J. Appl. Phys. **30**, 1 (1959).

CA11. Reflection of Inert Gas Ions from Copper.* R. C. BRADLEY AND E. RUEDL, *Cornell University.*—The study of the reflection of positive ions incident at 45° on a metal surface[1] has now been extended to Cu surfaces. Of particular interest are the following results: (a) the energy spread of the reflected ions was invariably less than 1 ev even for bombarding energies as high as 1000 ev; (b) despite this low energy, certain directional effects were evident which did not seem to exist for other kinds of secondary ions (e.g., Cu^+ or K^+) from the same surface; (c) the yield (defined as the ratio of reflected ion current measured at the final collector to incident ion current) decreased with increasing temperature in the range 20°–500°C and was reversible; (d) after the surface had been heated to 600°C for an hour the yield was much lower, but would build up again to a steady state value; (e) the yield was proportional to the background pressure of inert gas for pressures less than 1×10^{-5} mm Hg; (f) the yield increased with increasing bombarding energy up to about 250 ev and then slowly declined.

* This research was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
[1] D. S. Beers and R. C. Bradley, Bull. Am. Phys. Soc. Ser. II, 4, 221 (1959).

WEDNESDAY MORNING AT 11:00

New Yorker Terrace Room

(W. F. G. SWANN presiding)

Invited Papers

D1. Industrial and Scientific Applications of Nuclear Explosives. G. W. JOHNSON, *University of California, Livermore.* (40 min.)

D2. A Determination of the Age of the Elements. J. H. REYNOLDS, *University of California, Berkeley.* (40 min.)

WEDNESDAY MORNING AT 10:30

Statler-Hilton Penn Top South

(JAMES RAINWATER presiding)

Neutron Physics I, Mainly Apparatus

DA1. Versatile 4π Neutron Detector.* C. A. LUDEMANN, R. J. A. LEVESQUE,† AND JERRY B. MARION, *University of Maryland.*—A high efficiency, 4π neutron detector has been constructed which consists of 12 $B^{10}F_3$ proportional counters embedded in a 2-ft cube of paraffin. The response of this detector as a function of neutron energy has been measured in the range 0.1–2.5 Mev by observing the yield curves for the $T(p,n)$ and $Li^7(p,n)$ reactions, the absolute total neutron production cross sections for which have been accurately measured by Gibbons and Macklin.[1] These measurements indicate a flat ($\pm3\%$) response over the entire energy range studied. The detector has also been used to detect neutron thresholds for excited nuclear states by observing the slow threshold neutrons in the forward direction with a Li^6I scintillator surrounded by a B_4C shield. This "closed geometry" technique appears equal to the "open geometry "method[2] in sensitivity and superior in resolution.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at University of Montreal.
[1] J. H. Gibbons and R. L. Macklin, Phys. Rev. 114, 571 (1959).
[2] T. W. Bonner and C. F. Cook, Phys. Rev. 96, 122 (1954).

DA2. Filament Phosphor Neutron Spectrometer. R. D. EDGE,* *University of South Carolina.*—A neutron spectrometer has been constructed in which fast neutrons are incident along a bundle of fine glass tubes immersed in a hydrogenous liquid phosphor. Experimental results and calculations based on the geometry of the system indicate that the detector has good resolution ($\sim10\%$) and sensitivity ($\sim0.1\%$) and discriminates against gamma radiation.

* 1959 Summer Research Participant, Oak Ridge National Laboratory.

DA3. Gas Čerenkov Counter as a Threshold Detector for Bev Neutrons.* H. PALEVSKY AND D. J. HUGHES, *Brookhaven National Laboratory.*—The use of a gas-filled sensitive detector for Bev neutrons is now being investigated at the Cosmotron. The neutron energy is determined by threshold detection of protons produced by charge exchange in a converter, the Čerenkov threshold being investigated by variation of gas pressure. The success of the technique depends on the charge exchange cross section, both for production of neutrons in the internal Cosmotron target and for their detection in the Čerenkov counter. The counter is 90 cm long by 10 cm in diameter and contains CO_2 up to pressures as high as 100 atmospheres. Tests in an external proton beam have already shown that the counter has the correct threshold characteristics and that background pulses from scintillations in the CO_2 or counter materials are negligible. The counter is now in use at the zero degree position, in line with the Cosmotron "jump target," a location where neutron measurements can be made at the same time that the external beam is being used for other work. The energy distribution of neutrons produced in the beryllium jump target is now being studied and the charge exchange cross section will next be measured.

* Work carried out under the auspices of the U. S. Atomic Energy Commission.

DA4. Neutron Capture Gamma-Ray Anticoincidence NaI(Tl) Spectrometer. J. E. DRAPER AND C. O. BOSTROM, *Yale University.*—An anticoincidence NaI(Tl) gamma-ray spectrometer has been assembled and tested over the range 0.5–9 Mev with thermal neutron capture gamma rays. The central NaI(Tl) crystal, 2.4-in. diam by 6 in., and the surrounding NaI(Tl) anticoincident cylindrical annulus, 8-in. diam by 12 in. were fabricated by Harshaw Chemical Company in a configuration similar to that of Trail and Raboy.[1] Spectra of (n,γ) reactions from H, B^{10}, Cl, Fe, and Pb targets, with neutrons obtained from the electron linear accelerator, have given satisfactory results. The 8.58-Mev line from $Cl(n,\gamma)$ had a full width at half-maximum of 2.8%, and 14 of the $Cl(n,\gamma)$ lines have been clearly identified.

[1] C. C. Trail and S. Raboy, Rev. Sci. Instr. **30**, 425 (1959).

DA5. Measurement of Neutron Transport Cross Section by Crystal Spectrometer Techniques. W. L. WHITTEMORE AND A. W. MCREYNOLDS.*—The transport cross section σ_{tr}, defined as $\sigma_{tr}=\sigma_s(1-\langle\cos\theta\rangle)$, where σ_s is the scattering cross section and $\langle\cos\theta\rangle$ is the average cosine of the scattering angle, is usually determined by means of its relation to the neutron diffusion coefficient D or the neutron age τ. A determination of σ_{tr} by the more direct method of measuring the angular distribution of singly scattered neutrons has been performed. A well-collimated beam of monoenergetic neutrons was selected by a crystal spectrometer. A thin sample of the various materials (water, polyethylene, zirconium hydride) was used to scatter neutrons into the detector which measured the intensity as a function of angle for $30°<\theta<140°$. Sufficient data were taken to allow the computation of σ_{tr} for incident neutron energies of 0.05, 0.059, 0.090, 0.109, 0.139, and 0.170 ev. A comparison of the angular distribution of neutrons scattered by water and polyethylene for $E\sim0.06$ ev gives possible indication of the effects of "hindered rotation" of water molecules. The angular distributions will be compared with calculations now being made and with previous measurements.[1]

* John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California. Experimental work performed at Brookhaven National Laboratory.

[1] B. N. Brockhouse, Nuovo cimento **9**, Suppl. 1, 45 (1958).

DA6. Highly Polarized Neutrons at 125 Mev.* DOUGLAS MILLER AND RUSSELL K. HOBBIE,† *Harvard University.*—A beam of polarized neutrons has been produced by allowing the internal 164-Mev proton beam from the Harvard synchrocyclotron to strike a beryllium target. The neutrons produced in the forward direction are then polarized by scattering from carbon at 15°. When neutrons of energy greater than 110 Mev are selected by the detection process, the average beam energy is 125 Mev. An intensity has been obtained of 1.9×10^6 neutrons/in.^{2}/min through a 2 by 6 in. collimator. The beam polarization of 0.425 ± 0.020 represents a fivefold increase over polarized beams produced at this energy by other methods. The shielding techniques are also discussed.

* This work supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow (Cooperative).

DA7. Polarization of Neutrons Scattered from Li^6 and Li^7. S. E. DARDEN, T. K. DONOGHUE, AND C. A. KELSEY, *University of Notre Dame.*—The polarization $P(\theta)$ produced in the elastic scattering of neutrons from Li^6 and Li^7 has been investigated in the neutron energy region between 190 and 420 kev at a scattering angle of 88° in the laboratory system. Asymmetry measurements were made using neutrons from the $Li^7(p,n)Be^7$ reaction emitted at a laboratory angle of 50° and having an average energy spread of 44 kev. The polarization P_n of these neutrons for energies between 350 and 420 kev was obtained by averaging the published values[1] with the results of oxygen asymmetry measurements carried out in this laboratory. By using the resulting values of P_n, the corrected asymmetries for lithium were analyzed to give $P(\theta)$. In the case of Li^7, the $P(\theta)$ indicate that the parallel-spin (channel spin 2) interaction predominates in the S-wave scattering, while for Li^6 the antiparallel-spin (channel spin $\frac{1}{2}$) interaction is the stronger. For energies less than 350 kev, the measured asymmetries provide information on P_n, giving an approximately constant value of about 0.45 down to 250 kev, below which the polarization decreases abruptly.

[1] A. Okazaki, Phys. Rev. **99**, 55 (1955); Striebel, Darden, and Haeberli, Nuclear Phys. **6**, 188 (1958).

DA8. Statistical Independence of Energy Values of Opposite Parity.* N. ROSENZWEIG, *Argonne National Laboratory,* AND C. E. PORTER, *University of Minnesota.*—According to the statistical rule proposed by Wigner and further developed by us on the basis of a statistical madel for the energy matrix,[1] (1) levels of the *same* symmetry "repel" each other approximately according to the distribution $p(x)=\frac{1}{2}\pi x\exp(-\frac{1}{4}\pi x^2)$ and (2) levels of *different* symmetry are not correlated in position. We know of no experimental data which have a bearing on the propositon that the positions of nuclear levels of the same spin but of opposite parity are uncorrelated. Generally speaking, this point is also difficult to demonstrate for complex atomic spectra—for which, however, both parts of the rule have been tested thoroughly insofar as the quantum numbers S, L, and J are concerned.[2] However, the atomic spectrum of HfI is a notable exception in that the levels of even and odd parity are mingled sufficiently for a test to be made. One finds, in agreement with theory, that the probability per unit energy for a zero spacing in the combined system of levels is approximately equal to but not greater than one-half.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] C. E. Porter and N. Rosenzweig, Suomalaisen Tiedeakat. Toimituksia (to be published).
[2] N. Rosenzweig and C. E. Porter, Bull. Am. Phys. Soc. Ser. II, **4**, 353 (1958).

WEDNESDAY AFTERNOON AT 2:00

Statler-Hilton Penn Top South

(D. J. HUGHES presiding)

Neutron Physics II

E1. Isotopic Cross Sections in the kev Region.* E. G. BILPUCH AND H. W. NEWSON, *Duke University.*—The experiments with our new 160° collimator show an improvement in resolution over our older work by a factor of 5 in the energy region of 200 kev (~1 kev). Using natural elements and our newer apparatus many of our older measurements have been repeated. For favorable nuclides, our present resolution enables us to see theoretical peak heights for some resonances and for cases where resonances are very narrow the resonance takes the shape of our resolution function (half-width ~500 ev). Although we measure the total cross section of the normal element, we see much more detail than our earlier work which was done on isotopically pure samples of $Cl^{35,37}$, $K^{39,41}$, $Fe^{54,56}$, $Cr^{50,53,54}$ and Te^{130}. By comparing our present curves with our older measurements on isotopes, we are able to make isotopic assignments for most of the observed resonances. Under the present conditions, we are unable to run pure isotopes unless they exist in large quantities. Recently we obtained 30 g of Te^{130} and we measured the total cross section of this isotope up to 120 kev. Most of the cross section curves reported in this paper have been investigated as natural elements by more than one investigator, and a critical comparison of techniques has been based on a comparison of these data.

* Supported by the U. S. Atomic Energy Commission.

E2. Average Neutron Cross Sections in the kev Region.* KAMAL K. SEITH, E. G. BILPUCH, AND H. W. NEWSON, *Duke University.*—The 160° collimator at the Duke University 4-Mev Van de Graaff has been used to measure the average neutron cross sections in the energy region 1 to 200 kev, and also used as a 20° collimator to extend these measurements to 650 kev. The experiments were made with three different sample thicknesses, and the data simultaneously analyzed for R', and s- and p-wave neutron strength functions. Amongst the nuclei investigated so far are: Zn, Y, Zr, Nb, Mo, Rh, Pd, Ag, Cd, Sn, which confirm the existence of the $3p$ giant resonance in this region of atomic weight[1] and its spin orbit splitting[2] into $3p_{\frac{1}{2}}$ and $3p_{\frac{3}{2}}$. An extensive survey of heavy nuclei has been started and preliminary results for Nd, Gd, Pt and Au are found to be in excellent agreement with ev-region results[3] and have inherently smaller errors.

* This work was supported by the U. S. Atomic Energy Commission.
[1] Feshbach, Porter, and Weisskopf, Phys. Rev. **96**, 448 (1954).
[2] A preliminary report of this and the capture cross section work of Weston, Bilpuch, Seth, and Newson was made by K. K. Seth in the Proc. Florida Conference on the Nuclear Optical Model (1959).
[3] Hughes, Zimmerman, and Chrien, Phys. Rev. Letters **1**, 461 (1958).

E3. Effect of p-Wave Neutrons on Total Cross Sections in the kev Region. P. D. MILLER, J. H. GIBBONS, AND R. L. MACKLIN, *Oak Ridge National Laboratory.*—Recent measurements of neutron capture cross sections in the kilovolt range for $80<A<120$ have shown that the p-wave strength function peaks in this neighborhood. It will be the purpose of this paper to point out again[1] that p-wave neutrons are very important as a correction when determining s-wave strength functions by the average cross section method in the kilovolt region. The p-wave contribution to the total cross section is proportional to $E^{\frac{1}{2}}$, and the s-wave contribution is equal to a constant plus a term proportional to $E^{+\frac{1}{2}}$. In the case of Nb, the energy dependent terms are equal and $d\sigma/dE=0$ at 3 kev.

[1] A. M. Lane and J. E. Lynn, AERE Report T/R 2210 (1957).

E4. Strength Function and Resonance Parameters of Tellurium.* H. H. BOLOTIN AND R. E. CHRIEN, *Brookhaven National Laboratory.*—A most interesting region for investigation of the average characteristics of s-wave neutron interactions with nuclei is in the region $90\leq A\leq 140$, in which, measurements of s-wave strength functions differ most from optical model predictions.[1] In this region, we have determined the strength function for normal tellurium from the average cross section in the kilovolt region and resonance parameters. Preliminary results indicate substantial agreement with the trend exhibited by measurements on neighboring nuclei.[1] Final values will be presented and discussed. Samples of normal Te and those enriched in Te^{123} and Te^{125} were used. Neutron width determinations and isotopic identification were made of 11 resonances up to 429 ev. The $2g\Gamma_n^0$ values for levels in Te^{123} at 24.13, 35.97, and 158.8 ev are 10.9 ± 0.6, 2.33 ± 0.15, and 25.1 ± 3.3 mv, respectively. For levels at 72.61 ev in Te^{122}, 133.2 ev in Te^{124}, and 200 ev in Te^{126}, the Γ_n^0 values are 36.6 ± 3.9, 11.0 ± 1.1, and 88.5 ± 5.1 mv, respectively. Preliminary isotopic identification of resonances at 26.3, 218, 262, 288, and 429 ev lead to assignments to either Te^{125} or Te^{126}. Final identification and parameters for these levels will be presented.

* Work carried out under the auspices of the U. S. Atomic Energy Commission.
[1] Hughes, Zimmerman, and Chrien, Phys. Rev. Letters **1**, 461 (1958).

E5. Analysis of (d,p) Reactions.* C. R. LUBITZ, *University of Michigan.*—The neutron cutoff in the Butler (d,p) theory is interpreted as extinction of the incident wave when $r_n<r_0$, other distortion being neglected. Then, similar absorption must occur when the proton approaches the nucleus restricting the process also to $r_p>r_0$. To treat absorption while neglecting "refraction" we employ the continuity equation in which the real part of the optical potential plays no role. Assuming for the wave function a plane wave "modulated" by a real envelope function, an exact solution to the continuity equation which is the basis of a method for treating nucleon and deuteron elastic scattering and other direct reactions. The Butler "sharp cutoff" is replaced by one which is gradual and not spherically symmetric in r_n and r_p. Spherical averaging then gives simple closed-form results. Fitting (n,n), (p,p), (d,d), and (d,p) on beryllium and carbon yields: 1) conventional size nuclear radii; 2) reduced widths in the intermediate-coupling theory range; 3) small proton-nucleus interaction amplitudes; 4) energy-independent nuclear radii; 5) $C^{12}(d,p)$ polarization in agreement with experiment. These five aspects of the Butler theory are therefore improved without employing distorted waves.

* Supported in part by the U. S. Atomic Energy Commission.

E6. Inelastic Scattering of 14-Mev Neutrons from Carbon, Oxygen, and Lithium.* F. G. J. PEREY† AND P. LORRAIN, *Université de Montréal.*—Angular distributions of elastically and inelastically scattered neutrons from C^{12}, O^{16}, Li^7 have been determined. The measurements were made using an associated particle time-of-flight spectrometer. The $d(T,n)He^4$ reaction was used, the deuterons being accelerated to an energy of 170 kev by the University of Montréal Cockcroft-Walton accelerator.[1] Time to pulse height conversion was done and a 100 channel kicksorter recorded the time-of-flight spectrum. The time resolution obtained was 3 mμsec and

enabled resolution of the neutrons scattered from the first levels of the light elements studied. In all cases, the inelastic differential cross sections show large asymmetries indicating a direct interaction mechanism for the excitation of the levels studied. Comparison of the differential cross sections with the predictions of Glendenning's theory of direct interaction[3] will be made.

* This work was supported in part by the Canadian Atomic Energy Control Board.
† Holder of a National Research Council of Canada Scholarship.
[1] P. Lorrain *et al.*, Can. J. Phys. **3**, 299 (1957).
[2] N. K. Glendenning, Phys. Rev. **114**, 1297 (1959).

E7. Inelastic Scattering of Neutrons from Thorium-232.* ALAN B. SMITH, *Argonne National Laboratory.*—The inelastic scattering of neutrons from thorium-232 was studied using fast time of flight techniques. The incident neutron energy range was varied for 300 kev to 1.5 Mev in 150-kev increments. The total inelastic cross section was determined at each incident neutron energy. The inelastic scattering process leaving the residual thorium nucleus in the first excited (2+) state was examined in detail. The first excited level was measured to be 49 ± 2 kev above the ground state. The differential cross section for inelastic scattering to this level was symmetric about 90°. The excitation of the second (4+) thorium level at 165 ± 10 kev was also carefully studied. In addition levels in the residual nucleus at 730 kev, 810 kev, and 1100 kev (tentative values, accurate to ±50 kev absolute) were found to be appreciably excited by the inelastic scattering process.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

E8. Elastic Neutron Scattering from Oxygen and Nitrogen.* R. V. SMITH, L. F. CHASE, JR., R. H. ABRAMSON, J. B. REAGAN, AND M. WALT, *Lockheed Missiles and Space Research Laboratory.*—A pulsed-beam, time-of-flight method has been used to investigate the scattering of neutrons from oxygen and nitrogen. The elastic scattering differential cross section has been measured from 20 to 150°, for neutron energies of 5.0, 5.5, 6.0, and 6.5 Mev, with an energy spread of about 300 kev. Liquid oxygen and liquid nitrogen contained in specially constructed spherical Dewars were used as scatterers. Transmission measurements were made under the same experimental conditions, so that the total cross section could be compared directly with the integrated elastic cross section to give the total nonelastic cross section.

* Supported by the U. S. Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico.

E9. Anomalous Scattering of Ar^{36}.* R. E. CHRIEN, A. JAIN, AND D. J. HUGHES, *Brookhaven National Laboratory.*—The thermal scattering behavior of the element argon is unusual in that it has a large amount of incoherent scattering, even though it is practically monoisotopic and even-even. If the incoherence is ascribed to the rare isotope Ar^{36}, it must have an extremely large scattering length. Henshaw[1] reported that the total cross section of Ar^{36} at 0.076 ev, almost completely scattering, was indeed high, 77 barns. Measurements have now been made with the BNL fast chopper of a sample enriched in Ar^{36} for a wide range of neutron energy, to ascertain the origin of this unusual scattering cross section. The total cross section in the region 0.1 to 6×10^4 ev varies in a way that reveals the presence of a negative energy level. It is possible to explain the variation of cross section with energy, as well as the incoherence of the element, in terms of a single resonance at an energy of -5.4 kev with a reduced neutron width of 50 ev and a radiation width of 1.0 ev. The extremely large scattering cross section of Ar^{36}, which of course is completely coherent, implies that this isotope might have applications in neutron optics.

* Work carried out under the auspices of the U. S. Atomic Energy Commission.
[1] D. G. Henshaw, Phys. Rev. **105**, 976 (1957).

E10. Neutron Radiative Capture Measurements with the ORNL Fast Chopper. R. C. BLOCK AND G. G. SLAUGHTER, *Oak Ridge National Laboratory.*—The 28-in. diameter spherical liquid scintillator[1] installed at the 11.5 meter flight station of the ORNL fast chopper time-of-flight neutron spectrometer has been used to measure neutron radiative capture cross sections in the energy range from 10 to 20 000 ev. The radiative capture cross section of Pt has been measured from 0.2 to 17 kev with a resolution of ~0.2 μsec/meter; the cross section agrees in the 8–20 kev region to within 10% with previously reported Van de Graaff values. Previous capture measurements with 0.005-in. and 0.025-in. thick W samples had shown two peaks near the 18.8-ev resonance; recent measurements with a 0.001-in. thick W sample show only a single peak at this energy, indicating that the double peaks were caused by a thick target effect. Capture measurements are continuing in the 10 to ~200 ev region where individual resonances are observed and also in the kev region where "averaged-over-resonances" results are obtained.

[1] Paper B8 presented at the Neutron Capture Reactions Topical Conference of the American Physical Society, October 1–3, 1959.

E11. Thermal Neutron Capture in He^3. A. GALLMANN,* J. KANE, AND R. PIXLEY, *Brookhaven National Laboratory.*—Capture of low-energy neutrons by He^3 should go predominantly by the emission of $M1$ gamma rays except for an inhibition due to the fact that $\sigma_s(M1)\sim\langle C_A(He^3)C_A(He^4)\rangle^2 \times\sigma_{s.p.}(M1)$ where $\sigma_{s.p.}$ is the expected capture cross section for a neutron, and the C_A are the fractional amplitudes of the antisymmetric spatial wave functions of He^3 and He^4.[1] An alternate mode of capture can occur through the emission of electric monople electron positron pairs. These reactions have been investigated using a 3 in.×3 in. NaI(Tl) scintillator and two semicircular plastic scintillators viewing a He^3 gas target placed in an external neutron beam from the BNL reactor. The $M1$ reaction was measured by gating a 100 channel analyzer from pulses in the NaI corresponding to energy loss >10 Mev. For the EO reaction, triple 0.1 μsec coincidences were required to gate a 100 channel analyzer. Upper limits have been obtained of 100 μb and 2 μb respectively. By estimating $\Gamma\bar{p}(l=0)=2.0$ mev, the experimental upper limit to the $M1$ cross section indicates an inhibition of 10^3, which is consistent with $C_A(He^3)=C_A(He^4)\cong0.3$. A dimensional single particle estimate (Church and Weneser, private communication) yields an order of magnitude estimate of 3 μb for the EO cross section.

* On leave from Institut De Recherches Nucleaires, Strasburg.
[1] Flowers and Mandl, Proc. Roy. Soc. (London) **A206**, 131 (1951).

WEDNESDAY AFTERNOON AT 2:00

Statler-Hilton Gold Ballroom

(M. L. POOL presiding)

Radioactive Nuclei II

F1. Ground and First Excited States of Ag^{104}.* A. M. BERNSTEIN, O. AMES, M. H. BRENNAN, R. A. HABERSTROH, AND D. R. HAMILTON, *Princeton University.*—Enriched Pd foils were bombarded with protons to determine the origin of the ≈1-hr activity which was discovered in an even-A Ag isotope.[1] The only appropriate activity was found in Ag^{104} which was observed to have a 69 ± 3 min predominantly K-capture activity with intense γ rays of 550, 764, and 920 kev. The assignments of this activity[2] and the γ rays[3] have also been made by other techniques. By using atomic beam methods it was verified that the 69-min activity has $I=5$.[2] The $I=2$ resonance in Ag^{104},[1] when counted in an x-ray detector, was found to decay with a 69-min half-life with a small admixture of a 27-min component. When viewed in a β counter, only the 27-min component is observed. These characteristics of the $I=2$ resonance can be explained by placing the $I=2$ level above the $I=5$ level with an appreciable amount of isomeric transition. This interpretation is supported by the observation of feeding in the 764- and 920-kev γ rays which only occur in the decay of the $I=5$ state.

* Supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

[1] Reynolds *et al.*, Phys. Rev. **109**, 465 (1958).
[2] Ewbank *et al.*, Phys. Rev. **115**, 614 (1959).
[3] R. K. Girgis and R. van Lieshout, Nuclear Phys. (to be published).

F2. Hyperfine Structure Separations of 70-min Ag^{104} and 27-min Ag^{104m}.* O. AMES, M. H. BRENNAN, A. M. BERNSTEIN, AND D. R. HAMILTON, *Princeton University.*—The hyperfine structure separation of 70-min $I=5$, Ag^{104} has been measured using the atomic beam magnetic resonance method. A preliminary value of the hyperfine structure separation is $\Delta\nu=36\,000\pm3500$ Mc/sec. The sign of the moment was determined to be positive, and its value as obtained from the Fermi-Segrè formula is $\mu=+4.3\pm0.4$ nuclear magnetons. Preliminary results indicate that the magnetic moment of 27-min Ag^{104m} is $+4\pm2$ nm. A more accurate value of the moment and the value for the hyperfine structure separation will be given. The method of obtaining $\Delta\nu$ by observation of the multiple-quantum resonances as well as the method for determining the sign of the moments will be presented, and the question of the nuclear configurations for the two states will be discussed.

* Supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

F3. Spins and Moments of Odd-Odd Nuclei.* M. H. BRENNAN AND A. M. BERNSTEIN, *Princeton University.*—Magnetic moments for 32 odd-odd nuclei with $A<150$ have been calculated using empirical g factors and the standard jj coupling formula. Agreement (to within 0.3 nm) with the measured moment is found in 26 cases, and has been used to assign, unambiguously, the proton and neutron configurations for these nuclei. Excluding particle-hole configurations, we find Nordheim's "strong" rule obeyed in all cases where applicable. The analysis also indicates that Nordheim's "weak" rule should be replaced by a rule predicting a ground state of the highest or the lowest allowable spin. This rule is confirmed when applied to a wider class of nuclei[1] and indicates a small energy difference (of uncertain sign) between these states. This results in the frequent occurrence of isomerism when the "weak" rule is applicable. No cases of such doublets appear to occur when Nordheim's "strong" rule applies. We also find few cases where particle excitation, in competition with this angular momentum recoupling, is the cause of isomerism. These results will be discussed in terms of the spin-dependence of the residual proton-neutron interaction.

* Supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

[1] C. J. Gallagher, Jr., and S. A. Moszkowski, Phys. Rev. 111, 1282 (1958).

F4. Angular Correlation in the Decay of 5-hr Sb^{118}.* M. K. RAMASWAMY, D. L. HUTCHINS, AND P. S. JASTRAM, *The Ohio State University.*—We have measured the directional correlation between the 1.23-Mev and 1.03-Mev gamma rays, and the first-third correlation between the 1.23-Mev and 0.260-Mev gamma rays in Sn^{118} following the decay of the Sb^{118} ground state. The results for the Legendre polynomial expansion coefficients are as follows: for the 1.03–1.23 Mev cascade, $A_2=+0.137\pm0.012$ and $A_4=+0.014\pm0.010$; for the 0.26–1.23 first-third correlation, $A_2=+0.122\pm0.018$ and $A_4=+0.040\pm0.023$. These results, when combined, favor a 6-4-2-0 assignment, although the 4-2-2-0 and 3-2-2-0 sequences cannot be completely ruled out. Incidental to these studies, a search was made for positrons in coincidence with the 1.23-Mev gamma ray; an upper limit for positron emission was determined as 0.2% of the 1.23-Mev gamma decays, giving a partial lifetime lower limit of 2500 hr for direct positron decay to any of the excited levels in Sn^{118}.

* Supported by the U. S. Atomic Energy Commission.

F5. Beta-Gamma Angular Correlation Studies of Sb^{124}.* K. J. CASPER, W. L. SKEEL, AND P. S. JASTRAM, *The Ohio State University.*—Beta-gamma angular correlation measurements have been made on the $3(\beta)2(\gamma)0$ cascade in the decay of Sb^{124} as a function of the energy of the beta ray emitted in the first-forbidden nonunique 2.31-Mev transition. The energy dependence of the anisotropy is sensitive to the ratio of the first-forbidden matrix elements, to the approximation that only terms linear in the parameter ξ of Kotani and Ross need be retained, and to the presence of a contribution from third-forbidden matrix elements. The experimental results confirm the 3^- ground-state spin and parity assignments for Sb^{124}; they indicate the absence of an appreciable third-forbidden contribution; and they show that the ξ approximation fails in this case. The conclusions that can be drawn about the relative magnitudes of the first-forbidden matrix elements will be discussed.

* Supported by the U. S. Atomic Energy Commission.

F6. Alpha-Particle Emission Observed from Neodymium-144.* F. J. BRADLEY AND J. D. KURBATOV, *The Ohio State University.*—Nd_2O_3 enriched to 93.45% with Nd^{144} was obtained from Oak Ridge National Laboratory; 0.0154 g of Nd^{144} were plated out on a stainless steel planchet as Nd_2O_3. This sample was counted for alpha activity by a vibrating-reed electrometer in the rate of charge method of operation. The instrument was checked against an old polonium-210 standard which gave a calculated value in August, 1959, of 0.45 count per minute; the observed value the same month was 0.47 count per minute. A net counting rate of 0.0203 count per minute was obtained for the enriched $Nd_2{}^{144}O_3$ sample which gives assuming 50% geometry a $T_{\frac{1}{2}}{}^{Nd(144)}$ of 2.1×10^{15} yr. This agrees with the recent determinations of 1.5×10^{15} and

2.2×10^{15} yr obtained by nuclear emulsion techniques,[1,2] but not with the value of 2×10^{13} obtained using a liquid scintillation counter.[3] This latter value would appear to be too short on the basis of our results and those using nuclear emulsions.

* Use of facilities supported in part by the U. S. Atomic Energy Commission is acknowledged.
[1] Waldron, Schultz, and Kohman, Phys. Rev. **93**, 254 (1954).
[2] Von W. Porchen and W. Biezler, Z. Naturforsch. **11a**, 143 (1956).
[3] W. H. Kelly and G. B. Beard, Bull. Am. Phys. Soc. Ser. II, **4**, 324 (1959).

F7. Decay of Eu^{156}.* J. E. Cline and R. L. Heath, *Phillips Petroleum Company, Idaho Falls.*—Radiations following the decay of 15-day Eu^{156} have been studied using 180° permanent-magnet spectrometers and the techniques of scintillation spectrometry and of $4\pi\beta$ counting. Eu^{156} was prepared by two-week irradiations of Sm_2O_3 enriched to 99% in Sm^{154} in a high-flux region of the MTR (5×10^{14} n/cm²/sec). Approximately 25 gamma rays have been identified as transitions from excited levels in Gd^{156}. Measured gamma rays and their relative intensities are: 89 kev (5.33), 200 kev (0.23), 440 kev (0.03), 530 kev (0.02), 600 kev (0.11), 640 kev (0.35), 720 kev (0.31)*, 810 kev (0.50), 880 kev (0.09), 950 kev (0.18), 1060 kev (0.51), 1150 kev (0.71), 1230 kev (1.00)*, 1360 kev (0.07), 1660 kev (0.02), 1870 kev (0.10), 1950 kev (0.39)*, 2040 kev (0.19), 2140 kev (0.39), and 2200 kev (0.24). Those gamma rays marked with asterisks are possible unresolved groups of gamma rays. Gamma-gamma and beta-gamma coincidence studies of these gamma rays indicate definite levels in Gd^{156} at 89 kev**, 289 kev**, 730 kev, 1150 kev**, 1245 kev**, 1950 kev, 2040 kev, and 2230 kev. The levels marked with a double asterisk are also found in the decay of 5.6-day Tb^{156},[1,2] and from the radiation following neutron capture in Gd^{155}.

* Work supported by U. S. Atomic Energy Commission.
[1] Hansen, Nielsen and Sheline, Nuclear Phys. **12**, 389 (1959).
[2] S. Ofer, Phys. Rev. **115**, 412 (1959).

F8. Levels in Gd^{156} Excited in β Decay of Eu^{156}. G. T. Ewan, R. L. Graham, and J. S. Geiger, *Chalk River Laboratories.*—The conversion electron spectrum of Eu^{156} (15 days) has been studied at 0.1% resolution in the Chalk River $\pi\sqrt{2}$ β-ray spectrometer. Conversion lines have been observed corresponding to the internal conversion of γ rays of energies 88.97, 199.21, 599.5, 646.2, 709.9, 723.5, 811.8, 867.7, 960.6, 1040.7, 1049.5, 1065.1, 1079.3, 1154.0, 1168.4, 1230.8, 1242.4, 1877.0, 1937.8, 1965.8, 2026.1, 2097.8, 2180.8, and 2186.7 kev. The relative accuracy of these energy determinations is ~1 part in 7000. Gamma-gamma and conversion electron-gamma coincidence experiments together with energy sum considerations establish levels in Gd^{156} at 0(0+), 89.0(2+), 288.2(4+), 1154.0(2+), 1168.4, 1319.8, 1966.0(1 or 2), and 2186.7 kev. Additional levels are required to account for all the γ rays listed here. The first four levels listed are excited in the decay of both $Eu^{156}(\beta^-)$ and $Tb^{156}(\beta^+)$.[1] The higher energy level spectrum in Gd^{156} excited by the decay of Eu^{156} is different than that excited in the decay of Tb^{156}, suggesting different ground-state spins. The interpretation of the level scheme of Gd^{156} and its similarity to that of neighboring nuclei will be discussed.

[1] P. Gregers Hansen *et al.*, Nuclear Phys. **12**, 389 (1959); S. Ofer, Phys. Rev. **115**, 412 (1959).

F9. Conversion Electron Spectrum of Gd^{153}. R. L. Graham, G. T. Ewan, and J. S. Geiger, *Chalk River Laboratories.*—The conversion electron spectrum in Eu^{153} following electron capture in Gd^{153} (225 days) is being studied at ~0.15% momentum resolution using the Chalk River $\pi\sqrt{2}$ air-cored β spectrometer. Conversion lines are observed corresponding to transitions of 69.67±0.05 kev (98.2% $M1$+1.8% $E2$), 83.36±0.05 kev (57% $M1$+43% $E2$), 89.51±0.05 kev (>85% $M1$+<15% $E2$), 97.45±0.05 kev ($E1$), 103.18±0.05 kev (98.5% $M1$+1.5% $E2$) and 172.88±0.06 kev (~60% $M1$ +~40% $E2$). The 89.51- and 172.88-kev transitions have not been reported previously in the Gd^{153} decay. The multipolarity assignments are derived by comparing the experimental L subshell ratios with the theoretical values of Sliv. These results taken together with the earlier work, here and at other laboratories, on Sm^{153} and Gd^{153}, establish levels in Eu^{153} at 0 kev (5/2+), 83.36 kev (7/2+), 97.45 kev (5/2−), 103.18 kev (3/2+), and 172.88 kev (5/2+). The ratio of the reduced $M1$ transition probabilities from the 172.88-kev level (5/2+) to the two members of the ground state $K=5/2$ rotational band, at 0 and 83.36 kev, is ~0.15 which is smaller than the predicted value of 0.4 for a $K=3/2$ assignment to the 172.88-kev level. The 75.43-kev ($E1$) transition expected from the 172.88-kev level ($T_{\frac{1}{2}}=1.4\times10^{-10}$ sec) was not observed and a limit placed on its intensity indicates a hindrance factor of $>10^6$ with respect to the single-particle estimate.

F10. Radioactivity of Some Lutetium Isotopes. R. G. Wilson and M. L. Pool, *Ohio State University.*—Radioactive isotopes of lutetium have been produced by the irradiation of the enriched stable isotopes of ytterbium with 6-Mev protons. Preliminary measurements on these activities have already been presented. A more complete energy level scheme for the decay of Lu^{172} can now be presented which accounts for gamma rays with energies of 79, 91, 113, 182, 204, 270, 324, 373, 492, 528, 816, 907, 913, 1020, 1094, 1405, and 1587 kev. Extensive gamma-gamma coincidence measurements have led to the assignment of levels in Yb^{172} with energies of 530.7(6+), 903(8+), 1173(4+), 1665(3−), 1989(4+), 2080(6+), and 2193(5) kev in addition to the previously known 78.7- and 260.2-kev levels. An interpretation of the available information concerning the decay of Lu^{171} will be given. The complex gamma-ray spectrum of Lu^{170} has been examined. Gamma-ray energies, gamma-gamma coincidence measurements, and probable energy levels in Yb^{170} will be discussed. A maximum energy level of at least 3½ Mev in Yb^{170} is required, but no positron radiation has been detected. A new activity decaying by electron capture with a half-life of 7.1±0.2 min is assigned to Lu^{168}. The observed activity consists of the K x-ray of ytterbium and gamma rays with energies of 87, 900, 987, 1410, 1800, and 2130 kev. The possibility of levels of 87(2+) and 987(1) kev in Yb^{168} will be discussed.

F11. Search for Alpha Decay of Tungsten.* G. B. Beard and W. H. Kelly, *Michigan State University.*—According to work done using nuclear emulsion techniques, tungsten possesses a natural alpha activity corresponding to a half-life of $\alpha 2.2\times10^{17}$ y±50%, where α is the isotopic abundance of the isotope undergoing decay.[1] An attempt has been made to observe this activity using the self-scintillations of an artificial cadmium tungstate† and a natural (scheelite) calcium tungstate‡ crystal. The $CdWO_4$ crystal weighed 20.9 g and the $CaWO_4$ weighed 9.85 g. Both crystals gave good response to gamma rays. Considering the response of the tungstate crystals to the 5.3-Mev alphas of Po^{210} and the reported specific activity and alpha energy of the tungsten, the shape and location of the tungsten alpha peak could be estimated. It was expected that the height of the peak would be about twice background. However, no indication of a peak attributable to tungsten alpha activity has been observed. These preliminary results indicate that the tungsten half-life must be greater than $\alpha\times10^{18}$ yr.

* This research was supported in part by the United States Air Force through the Air Force Office Research of the Air Research and Development Command.
[1] W. Porchen and W. Riezler, Z. Naturforsch. **11a**, 143 (1956).
† Obtained from Linde Company.
‡ Obtained from Smithsonian Institution, Division of Mineralogy and Petrology.

F12. Direction of Alpha Emission from Oriented Np^{237} and the Quadrupole Coupling in $NpO_2Rb(NO_3)_3$. S. H. HANAUER, J. W. T. DABBS, L. D. ROBERTS, AND G. W. PARKER, *Oak Ridge National Laboratory.*—We have extended previous measurements[1] of the angular distribution of the alpha particles emitted by oriented Np^{237} nuclei in monocrystalline $NpO_2Rb(NO_3)_3$ into the temperature region 0.2–1.2°K. From paramagnetic resonance,[2] the spin Hamiltonian is $H=AI_zS_z'+P[I_z^2-I(I+1)]$, where $A=\pm0.16547$ cm^{-1} and $P=\pm0.03015$ cm^{-1}. Our observed temperature dependence of the magnitude of the alpha-particle anisotropy showed good agreement with the theoretical curve corresponding to the upper signs ($A<0$, $P>0$) and differed strongly from the curve associated with the lower signs.[3] This observed anisotropy also demonstrates that the alpha particles are emitted preferentially in the direction of the angular momentum vector of the oriented nucleus. Assuming that the Np^{237} nucleus is prolate ($Q>0$) and also that K has a value close to I, the foregoing result corresponds to preferential alpha emission from the tips of the nucleus.[4]

[1] Roberts, Dabbs, and Parker, *Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy* (United Nations, Geneva, 1958), Vol. 15, p. 322; and Dabbs, Roberts, and Parker, Physica **24**, 569 (1958).
[2] Bleaney, Llewellyn, Pryce, and Hall, Phil. Mag. **45**, 992 (1954).
[3] M. H. L. Pryce, Phys. Rev. Letters **3**, 375 (1959).
[4] Hill and Wheeler, Phys. Rev. **89**, 1102 (1953), especially p. 1133.

F13. Emission of Alpha Particles from Oriented Np^{237} Nuclei and the Structure of the NpO_2^{++} Bond. L. D. ROBERTS AND J. W. T. DABBS, *Oak Ridge National Laboratory.*—Pryce has suggested that P is positive for $NpO_2Rb(NO_3)_3$ (see preceding abstract) and further that this arises from a nuclear quadrupole moment $Q<0$ and a covalent bond of essentially σ character for the NpO_2^{++} group, i.e., $\zeta=\langle|Y_{20}/r^3|\rangle$ positive. Our results on alpha emission and fission (following abstract) may be correlated more naturally with current nuclear concepts by the assumption $Q>0$, however. This requires ζ to be negative. By using an IBM 704 code formulated by S. Cohen, we have calculated the 5*f*, 6*d*, 7*s*, and 7*p* relativistic Hartree wave functions in U^{5+}. Those for Np^{5+} should be similar. By using these functions, ζ has been calculated for a number of possible models for the NpO_2^{++} bond. In some cases the relativistic small component plays an important role and it is found that P electrons give a ζ roughly an order of magnitude larger than the other states. Thus the sign and magnitude of ζ would be sensitive to a small percentage of P hybridization. We note that an assumption of a small but predominantly π admixture of P state would permit ζ to be negative for an otherwise predominantly σ.

F14. Fission Fragment Emission from Aligned U^{233} and U^{235} Nuclei. J. W. T. DABBS, F. J. WALTER, L. D. ROBERTS, AND G. W. PARKER, *Oak Ridge National Laboratory*, AND J. O. THOMSON, *University of Tennessee.*—A new apparatus has been used to restudy the angular anisotropy of fission fragments produced by thermal neutron bombardment of U^{233} in monocrystalline $UO_2Rb(NO_3)_3$ in the temperature range 77°K–1.3°K. In the new apparatus a germanium surface-barrier counter 1 in. in diameter was held at 77°K while the sample crystal temperature was varied. A thin (0.22 mg/cm^2) nickel window separated the sample space (containing He^4 heat exchange gas) from the counter (*in vacuo*). The apparatus was designed so that variation in sample temperature caused negligible motion of the sample in the neutron beam. Thus, two important possible sources of systematic error were removed. In accord with the earlier results,[1] the U^{233} measurements show that the fragments are emitted isotropically within ~1%, even while α particles from the same sample are strongly anisotropic. Similar measurements on U^{235}, however, yield a different result: there is a substantial anisotropy for fission fragments, opposite in sign to and smaller in magnitude than that for the α particles. This result is in general accord with the ideas of Bohr.[2]

[1] Parker, Roberts, and Dabbs, Bull. Am. Phys. Soc. Ser. II, 3, 6 (1958), see papers A1 to A3.
[2] A. Bohr, *Proceedings of the First International Conference on the Peaceful Uses of Atomic Energy*, Geneva, Switzerland (United Nations, New York, 1956), Vol. 2, p. 151.

WEDNESDAY AFTERNOON AT 2:00

New Yorker Grand Ballroom

(O. PICCIONI presiding)

Cosmic Rays

FA1. Acquirement of Cosmic-Ray Energies. W. F. G. SWANN,* *Bartol Research Foundation.*—The speculations here presented invoke only conservation of energy as applied to the destruction of a magnetic field and the transfer of the energy to a form represented by the sum of the ordinary relativistic kinetic energies of the particles originally concerned in producing the currents responsible for the field. Consider two rings of gas of cosmical dimensions, possessing the same axis to which the planes of the rings are perpendicular. The rings carry oppositely directed currents, but they are approaching in opposition to the repulsion until they finally coincide with the destruction of the field as a consequence. The energy goes into the form of ordinary relativistic kinetic energy of the particles. If the ionic density is small, the mean free path is so great as to result in very little conversion of energy to radiation before the particles are completely dispersed. By considering rings with radius of the order 10^{10} cm, with radius of the conducting path of the order 10^9 cm, and with ionic density of the order of 10 ions per cc, it is possible to realize conditions in which individual particle energies of the order of 10^{13} ev or more are obtained.

* Assisted by the Office of Naval Research.

FA2. Geophysical Implications of the Distribution of Congential Malformation. J. P. WESLEY, *Lawrence Radiation Laboratory.*—In the absence of any known mechanism other than ionizing radiation for producing genetic damage in mammals, it may be postulated that the fraction of malformed births (deaths due to congenital malformation divided by births) is proportional to background radiation. The distribution of congenital malformation may then be used in lieu of a survey with completely unshielded ionization chambers placed on the ground. The world-wide incidence of congenital malformation is such a function of geomagnetic latitude as to indicate that radioactivity on the surface of the earth is produced entirely by the flux of cosmic-ray energy. Lines of

equal incidence of congenital malformation show anomalies which correspond to lines of equal annual secular change in the magnetic declination. If these isoporic lines are coincident with current lines in the earth's core, then the anomalies may be explained; and further credence may be given to the hydromagnetic dynamo theory of the origin of the earth's field. From these findings the age of the earth cannot be determined from the radioactivity age of certain minerals.

FA3. Seasonal Variation of Cosmic-Ray Intensity in Polar Regions.* V. PATEL AND K. MAEDA, *University of Maryland.*—Cosmic-ray muon data at Thule (geomag. lat. 89°N) and at Wilkes (geomag. lat. 76°S) were obtained by cubical G-M telescopes since January, 1958. Daily averages of these data, corrected for barometric effects, show clear seasonal variations which are in antiphase with each other. The diurnal variations at these stations also show peculiar seasonal variations, with a significant increase of the amplitude around equinox, even if the data corresponding to magnetically disturbed days are subtracted to correct for the high occurrence of magnetic storms around equinox. Contributions of atmospheric temperature effects on these variations are shown, by making use of radio sonde data near these stations. It is also shown that there is a residual diurnal variation of extraterrestrial origin. Comparing with other analyses, the latitude dependence of the diurnal variation will be discussed.

* Supported by NSF-IGY grant.

FA4. Cosmic-Ray Produced Rare Gases in an Iron Meteorite.* PETER SIGNER AND ALFRED O. NIER, *University of Minnesota.*—The absolute amounts and the isotopic composition of cosmic-ray produced argon, neon, and helium have been measured as a function of depth in the half-ion iron meteorite Grant. The samples were completely vaporized and the purified gas mixture analyzed in a calibrated mass spectrometer operated under static conditions. From the center to the surface of the meteorite, a distance of approximately 25 cm, the argon and neon contents increase 25 and 45%, respectively. The Ar^{36}:Ar^{38} ratio increases 6% whereas the Ne^{20}:Ne^{21}:Ne^{22} appears to be constant. At the center, the Ar^{36}:Ar^{38} ratio is 0.61 and the Ar^{38} and Ne^{21} amounts are 27.4 and 5.10×10^{-8} cc (NTP)/g. The He^3 and He^4 determinations confirmed earlier findings.[1,2] The results will be discussed in terms of a model earlier proposed and will also be compared with the results for proton bombarded targets.

* Research support in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] J. H. Hoffman and A. O. Nier, Phys. Rev. 112, 2112 (1958).
[2] E. L. Fireman, Planetary Space Sci. 1, 66 (1959).

FA5. Cosmogenic Nuclear Reactions in Iron Meteorites.* DAVID E. FISHER AND OLIVER A. SCHAEFFER, *Brookhaven National Laboratory.*—The cosmogenic He^3, He^4, Ne^{21}, Ne^{22}, Ar^{36}, and Ar^{38} isotopes have been measured mass spectrometrically in seven iron ataxites. An attempt at analysis is made based on nuclear reactions induced by high-energy protons. A combination of He^3/He^4, He^3/Ar^{38}, and Ne^{21}/Ar^{38} ratios are used as a measure of the energy and intensity of the incident radiation. Factors contributing to anomalous ratios are discussed. Exposure ages are deduced on the basis of these ratios, total isotopic abundances, and previously measured Cl^{36} values.

Meteorite	He^3 sec $\times10^{-8}$/g		He^3/He^4	He^3/Ne^{21}	He^3/Ar^{38}
Forsyth	48	±6	0.32	83	23
Santa Catherina	57	±6	0.25	121	22
Santa Rosa	47	±5	0.26	107	21
Smithland	58	±4	0.28	94	22
Tombigbee	4.7	±1	0.14	61	13
Tucson	13	±1	0.09	16	25
Washington	193	±20	0.067	94	26

* Research performed under the auspices of the U. S. Atomic Energy Commission.

FA6. Cross Section for High-Energy Cosmic Rays in the Atmosphere. ROBERT W. WILLIAMS,* *University of Washington.*—The cross section of light nuclei for cosmic-ray protons in the multi-Bev region has been calculated, using the recently available electron-scattering results on the charge density in light nuclei. Elementary nucleon-nucleon cross sections are available from accelerator studies up to 9 Bev,[1] and at somewhat higher energies they can be inferred from certain cosmic-ray measurements[2]; the inelastic (pp) cross section has a nearly constant value, around 25 mb, from a few Bev to at least some tens of Bev. For $\bar{\sigma}=25$ mb, the collision mean free path in air is $\lambda=109$ g cm^{-2}. Even for $\bar{\sigma}$ as high as 40 mb, one has $\lambda=88$ g cm^{-2}. Such relatively long collision lengths change the usual picture of cosmic rays in the atmosphere to some extent: (1) one argument for high average elasticity of collisions is weakened; (2) an appreciable number of primary protons penetrate to mountain altitudes without interacting. The flux of "pure" protons of >100 Bev, at 700 g cm^{-2}, should be $\sim$0.02 m^{-2} sec^{-1} sterad^{-1}.

* On leave of absence from Massachusetts Institute of Technology.
[1] *Proceedings of the International Conference on High-Energy Physics* (CERN, Geneva, 1958), p. 74.
[2] A. E. Brenner and R. W. Williams, Phys. Rev. 106, 1020 (1957).

FA7. Intensity of High-Energy Mu Mesons at Large Zenith Angles.* W. R. SHELDON AND N. M. DULLER, *University of Missouri.*—A cosmic-ray underground experiment is being conducted to investigate the intensity of high-energy mu mesons within zenith angle range 66°–72°. A large but effectively narrow-angle telescope is in operation in a covered rock quarry near Valmeyer, Illinois. Particles recorded by the apparatus are incident essentially normally on a steep bluff which bounds the quarry on the west and must traverse great thicknesses of rock of known composition. The amount of rock to be traversed can be varied by selection of telescope site within the quarry. Preliminary results at average zenith angle 69° are as follows: at 280 MWE (meters water equivalent) the intensity is $5.23\pm0.46\times10^{-5}$ cm^{-2} sterad^{-1} sec^{-1}; at 390 MWE the intensity is $2.74\pm0.38\times10^{-5}$ cm^{-2} sterad^{-1} sec^{-1}. These intensities are higher than previously reported vertical intensities at the corresponding depths and are interpreted as evidence of high-energy pi meson decay-absorption effects in the atmosphere which enhance the mu meson intensity at large zenith angle.

* Supported in part by the Research Corporation, the Alfred P. Sloan Foundation, and the U. S. IGY Program.

FA8. Interactions of Extensive Air Showers of the Cosmic Radiation in Water.* JOHN R. GREEN, ROY THOMAS, AND JAMES R. BARCUS, *University of New Mexico.*—Two scintillators, each 10 ft in diameter, form a vertical telescope with an 11-ft separation. Provision is made for a variable amount of absorber between the two scintillators of up to 5 ft of water. Spectra are obtained for the number of particles observed in the lower scintillator as a function of various ranges of particle numbers in the upper scintillator. Preliminary results indicate that the larger air showers are not fully developed at an atmospheric depth of 840 g/cm^2. Details of the spectra will be shown.

* Supported by the Air Force Office of Scientific Research.

FA9. Investigation of the Electrical Signals Produced by Air Showers. J. F. AHEARNE,* *Cornell University.*†—Wilson[1] suggested using the lower atmosphere and the electric field therein to make a large ionization chamber. An air shower will produce ionization which will affect the field. The change in the field may be sufficient to be observed with a probe located near the shower. Two signals might be observed, the first due to the rapid electron movement and the second due to the slow ion movement. A probe was located in the lower atmosphere near the center of an air-shower measuring system.

The signal from an electrometer-fed amplifier was recorded and compared with the size and location of 94 air showers. No conclusive correlation was found, probably due to insufficient sensitivity.

[1] R. R. Wilson, Phys. Rev. **108**, 155 (1957).
* General Electric Coffin Fellow.
† Now at the Air Force Special Weapons Center, Albuquerque.

FA10. Nuclear Interactions of High-Energy Cosmic Rays.* WILLIAM L. PAK AND KENNETH I. GREISEN, *Cornell University.*—Nuclear interactions of charged cosmic rays of 30-Bev median energy have been observed near sea level using a multiplate cloud chamber mounted under a magnet spectrometer. The observations wer carried out with the spectrometer in two orientations, 0° and 68° to the vertical. At 68° one expects the N component to have been filtered out by the atmosphere and essentially all interactions to be due to muons. Under this condition only two events were obtained, indicating a cross section of about 2×10^{-29} cm²/nucleon. This is consistent with the Williams-Weizsacker picture. In the vertical direction the number of interactions was larger, indicating that the interactions were primarily due to N component rather than to muons; and the signs of interacting particles were predominantly positive, suggesting that these particles were mainly protons. The number of charged N particles was found to be about 1% of the number of muons. This is a considerably higher proportion of N component than would be inferred from the experiment of Mylroi and Wilson† in lower energy regions.

* This work was supported by a grant from the National Science Foundation.
† M. G. Mylroi and J. G. Wilson, Proc. Phys. Soc. (London) **A65**, 404 (1951).

FA11. Nuclear Interactions and Mean Free Path of 200-Bev Protons.* M. W. TEUCHER AND E. LOHRMANN, *University of Chicago.*—In a stack of 22 liters of Ilford G-5 emulsion flown for 13 hr in Texas at an altitude of 116 000 ft, 14 fragmentations of heavy nuclei having an energy $E>70$ Bev/nucleon have been located. The energy of the heavy nuclei has been determined by relative scattering measurements between the fragments. The protons among the fragments having angles $<2\times10^{-3}$ radian have been followed along the tracks. From the number of the observed neutral interactions within the same solid angle, the contribution of deuterons and tritons can be estimated to be <30%. The mean free path for inelastic nuclear interactions in nuclear emulsion is 42 ± 10 cm at an average proton energy of about 200 Bev. The angular distribution of the shower particles in the observed secondary interactions was measured. The energy determined from the angular distribution was compared with the energy obtained by relative scattering measurements. The average multiplicity of shower particles was found to be 12.1 ± 2.5.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and by the National Science Foundation.

FA12. Nucleon-Nucleon Interactions at Energies Greater Than 10^{12} ev.* P. L. JAIN,† *University of Chicago.*—In a stack of 22 liters of Ilford G-5 emulsion flown from Brownwood, Texas, a nuclear interaction of type $2+16p$ was observed, the track length of which is about 1.0 cm per plate. By following the central cone of the shower tracks, which could be followed for more than 24 cm inside the stack, an energetic secondary interaction of type $2+16p$ was found along with other low-energy interactions. High-energy electron cascades, originating most probably from the decay of π^0 mesons produced in the primary interaction, were also observed from the primary event. Both the primary and the secondary interactions are considered as nucleon-nucleon interactions. The energy of both these events, as determined from the angular distribution of shower tracks, is of the order of 3.2×10^{12} ev. Owing to the favorable geometry of these events, extensive multiple and relative scattering measurements were possible. Complete analysis of both of these events, including energy, transverse momentum, and angular distribution of shower particles in the CMS, along with the analysis for the test of the two fire ball model, will be presented.

* Supported in part by the National Science Foundation and the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† On leave of absence from the University of Buffalo.

WEDNESDAY AFTERNOON AT 2:00

Statler-Hilton Skytop Room

(SEYMOUR KOENIG presiding)

Metals; Dislocations; Radiation Damage

G1. Double Bragg X-Ray Scattering from Cold-Worked Iron.* W. T. OGIER, R. L. WILD,† AND L. M. RICHARDS, *University of California, Riverside.*—Double Bragg x-ray scattering at small angles has been studied in iron recrystallized below the alpha-gamma transformation temperature using iron and cobalt $K\alpha$ radiation. Scattering intensities are comparable to those from cold-worked nickel.[1] The onset of scattering from stretched specimens accompanies the yield phenomenon and appears more suddenly than scattering from nickel. A small anisotropy of scattering from rolled specimens is observed. Annealing of cold-worked specimens appears to be critically dependent on the presence of oxygen or nitrogen in the iron. The small thicknesses of specimens used (0.001 to 0.003 in.) has facilitated outgassing by vacuum annealing in the presence of getters. Preliminary data indicate that annealing after cold work in macrocrystalline alpha-iron originates from initial blocks after reductions of the order of 50%. This behavior is similar to that previously observed in nickel.[2]

* Supported by the Office of Ordnance Research, U. S. Army.
† Now on leave to the University of Illinois.
[1] Ogier, Wild, and Nickel, J. Appl. Phys. **30**, 408 (1959).
[2] Wild, Ogier, and Nickel, Bull. Am. Phys. Soc. Ser. II, **4**, 264 (1959).

G2. Fermi Surfaces in Zinc and in Cadmium. WALTER A. HARRISON, *General Electric Research Laboratory.*—Fermi surfaces have been constructed using a single-OPW approximation (analogous to the nearly-free-electron approximation). The most prominent set of de Haas-van Alphen oscillations observed in zinc can be directly interpreted in terms of needle-shaped surfaces containing electrons in the combined third and fourth bands. This interpretation is consistent with the observed period and cyclotron mass and with the observed dependence of the period on temperature and on alloying, but is in apparent disagreement with the dependence upon

pressure. These needle-like segments are not expected to occur in cadmium, for which the most prominent oscillations are associated with arm-like surfaces containing holes in the combined first and second bands. The cross section of these arms and their orientation are consistent with the values determined experimentally by Berlincourt.[1] Knowledge of the higher frequency de Haas-van Alphen oscillations in zinc is insufficient at present to allow a unique interpretation in terms of this picture.

[1] T. G. Berlincourt, Phys. Rev. **94**, 1172 (1954).

G3. Calculation of Order Parameters in a Binary Alloy by the Monte Carlo Method. LLOYD D. FOSDICK, *University of Illinois.*—A Monte Carlo sampling scheme similar to that used by Metropolis, Wood, and others in equations of state computations for gases has been used to investigate order-disorder phenomena in a face-centered cubic A_3B alloy. The model of the alloy assumes that the structure of the lattice is fixed and that interactions exist between first neighbors and second neighbors only. In most of the calculations detailed consideration is given to an array consisting of five unit cells on an edge (five hundred sites) with periodic boundary conditions. The long-range order and short-range order for first and second neighbors has been computed above and below the critical temperature. Using the conventional energy parameter

$$v_n = \frac{V_{AA}^{(rn)} + V_{BB}^{(rn)}}{2} - V_{AB}^{(rn)}$$

for nth neighbors it is found that $v_2/v_1 = -0.25$ and $v_1 = 816$ cal/mole gives the best agreement with experiments on Cu_3Au. The critical temperature appears to vary linearly with the ratio $2/v_1$.

G4. Quenched-in Point Defects in Beta Phase Au-Zn Alloys.* D. S. LIEBERMAN, KALINATH MUKHERJEE, AND T. A. READ, *University of Illinois.*—Rapid quenching from high temperatures was found to "freeze-in" excess point defects in near equiatomic beta phase Au-Zn alloys. The activation energy of formation was determined from electrical resistivity measurements and the activation energy of motion from isothermal annealing of excess resistivity and volume change. The annealing kinetics were first order at all quenching temperatures used. The concentration of defects calculated from the formation energy was of the order of one atomic percent when extrapolated to the melting point. A correlation between this concentration and the quenched-in increase in electrical resistivity gives ~ 1.5 $\mu\Omega$ cm per atomic percent defects. A lattice relaxation of about 50% of the atomic volume around the vacant sites was obtained from x-ray lattice parameter measurements and the number of defects calculated from the corrected quenched-in excess volume change agreed with that calculated from the formation energy resistivity measurements. The concentration of defects in Au-Zn is an order of magnitude higher than that for pure Au and Al, and comparable to that in beta phase Au-Cd.[1]

* Supported in part by the U. S. Atomic Energy Commission.
[1] W. J. Storm and M. S. Wechsler, J. Appl. Phys. **28**, 1509 (1959).

G5. Dislocation Contribution to the Elastic Constants and Damping at 10 Mc. G. A. ALERS, *Ford Motor Scientific Laboratory,* AND D. O. THOMPSON, *Oak Ridge National Laboratory.*—The ultrasonic pulse technique was used to measure the three single crystal elastic constants and their associated attenuations in well annealed and cold worked copper from 4.2°K to 250°K. Following the method of Thompson and Holmes,[1] neutron irradiation was used to determine the dislocation contribution. The results on annealed material show evidence of an internal friction peak with a maximum near room temperature at 10 Mc. Lücke and Granato[2] have predicted that such a peak is to be expected from highly damped, resonant bowing of dislocation loops. Using this interpretation, the magnitude and temperature dependence of the friction force on a moving dislocation have been estimated. In the cold-worked specimen, the Bordoni peak was found to be near 130°K at 10 Mc in agreement with the recent results of Bordoni *et al.*[3]

[1] D. O. Thompson and D. K. Holmes, J. Appl. Phys. **27**, 713 (1956).
[2] K. Lücke and A. Granato, J. Appl. Phys. **27**, 583 (1956).
[3] Bordoni, Nuovo, and Verdini, Phys. Rev. Letters **2**, 200 (1959).

G6. Determination of Dislocation Densities in Silicon Crystals by an Optical Method. G. ECKHARDT AND S. LEDERHANDLER, *Radio Corporation of America* (introduced by E. O. Johnson).—Photoelastic studies on silicon crystals and the determination of dislocation densities in these crystals by chemical etching have indicated a correlation between the dislocation densities and the crystal residual stress. Because the distribution of etch pits in silicon is nonuniform, the determination of an average etch pit density is either time consuming or inaccurate. Hence, a study was made to see whether the correlation mentioned above could be used to determine the average dislocation densities in silicon crystals by a photoelastic measurement. The average dislocation density is a single parameter for any given crystal sample; therefore, one has to look for a corresponding single parameter of the photoelastic interference pattern. It was found that the average light intensity which is transmitted through a sample placed between crossed polarizers in a convergent beam is a suitable parameter of this kind. After calibration against the dislocation density values found by elaborate etch pit counts, it is now possible to determine average dislocation densities of a specimen between 10^2–10^6 cm^{-2} by a single photometer reading. This optical method provides a procedure for routine measurements exceeding the speed and accuracy of the chemical method.

G7. Influence of Imperfections on the Production and Recovery of Radiation Damage in Copper.* R. M. WALKER AND J. W. CORBETT, *General Electric Research Laboratory.*—We have studied the production of damage at 20°K and 80°K in samples of copper which differ in their imperfection content. The recovery was followed to 400°K. The samples consisted of a zone refined "pure" specimen, a non-zone refined "impure" specimen, and a highly cold-worked specimen. The damage production rate at 20°K was the same within 5% for all samples. However, at 80°K the production curves were found to differ radically. The pure sample shows the least damage. An analysis of these results based on the trapping of mobile interstitials will be presented. In the recovery, stage I (20°K–80°K) was suppressed for both the cold-worked and impure samples. Little stage II (80°K–250°K) recovery was observed in the pure and cold-worked samples. In the impure sample, however, 40% of the recovery above 80°K occurred by 170°K. This is interpreted as the release of trapped interstitials. All samples show a marked stage III (250°K–350°K) recovery. In both the pure and impure samples essentially complete recovery is achieved by 350°K. In the cold-worked sample the net resistivity left after stage III is less than that prior to irradiation. These results demonstrate the importance of trace imperfections in damage experiments (particularly these in which the temperature permits migration during bombardment).

* Sponsored by U. S. Air Force Cambridge Research Center.

G8. Infrared Studies of Electron Irradiated Silicon I. J. W. CORBETT, G. D. WATKINS, AND R. M. CHRENKO, *General Electric Research Laboratory.*—We have examined the IR absorption spectrum (1.4–14 μ) of silicon irradiated at room temperature with 1.5 Mev electrons. A sharp band at 12 μ

is produced whose intensity is roughly proportional to the concentration of dissolved oxygen originally in the silicon. The production rate of this band *vs* irradiation correlates with that of the defect previously studied in spin resonance (*A* center) and in electrical measurements (net acceptor at $E_c-0.17$ ev), which has been shown to be strongly dependent upon oxygen content.[1] The annealing behavior of the 12 μ band is similar to that of the other measurements again suggesting that they arise from the same defect. In a sample enriched with 14% O^{18}, a small subsidiary peak is observed which identifies the 12 μ absorption as arising from the vibration of a single oxygen atom. These data lend support to the model proposed from spin resonance studies that the *A* center, which is the dominant defect produced by irradiation in pulled silicon, involves an oxygen atom trapped in a lattice vacancy.

[1] Watkins, Corbett, and Walker, J. Appl. Phys. **30**, 1198 (1959); G. Bemski, *ibid.* **30**, 1195 (1959); G. K. Wertheim and D. N. E. Buchanan, J. Appl. Phys. **30**, 1232 (1959).

G9. Infrared Studies of Electron Irradiated Silicon II. G. D. WATKINS, J. W. CORBETT, AND R. S. MCDONALD, *General Electric Research Laboratory.*—The annealing of the 12 μ band discussed in the previous abstract has been studied. The first stage (~300°C) consists of the disappearance of the 12 μ band and the emergence of a new band at 11.3 μ of approximately the same intensity. It is primarily in this stage that the spin resonance center anneals and electrical properties recover.[1] It is clear, however, that the sample has not been returned to its initial state. During subsequent higher temperature annealing (~500°C), the 11.3 μ band disappears and a succession of bands between 11.3 and 9 μ emerge and disappear. During the second stage the 9 μ band associated with oxygen in its original state is also observed to diminish. A model of these annealing stages will be presented which is also consistent with the identification of the 12 μ band as arising from an oxygen trapped in a lattice vacancy.

[1] G. Bemski and W. M. Augustyniak, Phys. Rev. **108**, 645 (1957).

G10. Numerical Investigations of Radiation Damage in an Atomic Model.* G. H. VINEYARD, J. B. GIBSON, A. N. GOLAND,† AND M. MILGRAM, *Brookhaven National Laboratory.*—A program is under way to explore fundamentals of radiation damage by numerically integrating, on a high-speed computer, the classical equations of motion of a set of about 500 atoms. Pairwise Born-Mayer repulsions and an attractive energy proportional to volume are assumed, together with elastic and dissipative forces at the boundary. Crystalline copper is being represented. One atom is given initial kinetic energy, and the motion is followed until a quiescent damaged state is reached. A number of near-threshold events have been investigated. Focusing collisions are prominent, and replacements outnumber displacements. The lowest threshold for displacement occurs when initial velocity is in the ⟨100⟩ direction. Agitations which are seen resemble thermal spike but are incompletely randomized. Localized vibrational modes associated with the defects retain their excitation and may cause annealing. The various close Frenkel pairs and the possibilities of crowd ion production are being investigated. Static configurations of defects are also studied.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Guest from Ordnance Materials Research Office.

G11. Solution of Many-Body Problems on Digital Computers.* M. MILGRAM, G. H. VINEYARD, J. B. GIBSON, AND A. N. GOLAND,† *Brookhaven National Laboratory.*—Classical many-body problems with short range central forces are solved on the IBM-704. The program allows for any number of bodies up to 1000 and for arbitrary force laws. Input is a set of initial particle positions and velocities, the force law, and various boundary forces. Integration is done by a central finite difference approximation with arbitrary time step. With 500 bodies, one step takes one minute of computer time; typical runs require 50 to 250 time steps. A cathode-ray tube can be used to display the particle orbits, and kinetic and potential energy are calculated in special edits. Configurations of static equilibrium are found automatically as asymptotes. It is anticipated that by recoding the speed can be increased fourfold and the particle capacity can be doubled. By taking advantage of all symmetries the particle capacity in some runs can be made even much larger. The techniques and subroutines developed here are applicable to problems in statistical mechanics for systems with short range forces.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Guest from Ordnance Materials Research Office.

G12. Focusing Collisions in the Radiation Damage of Copper.* A. N. GOLAND,† M. MILGRAM, G. H. VINEYARD, AND J. B. GIBSON, *Brookhaven National Laboratory.*—Methods discussed in the preceding abstracts have been used to investigate the effects of a knock-on atom in copper with kinetic energy of 25 ev or somewhat above. Focusing collisions in ⟨110⟩ directions were consistently observed, verifying Silsbee's predictions based on an isolated line of hard spheres. Focusing collisions were also observed to occur in ⟨100⟩ directions. The latter type of focusing had not been predicted; it results from interactions with atoms in adjacent lines, and is more rapidly damped than the ⟨110⟩ type. The range of collision chains in ⟨110⟩ lines was investigated by starting knock-ons in ⟨110⟩ at energies up to 400 ev. Energy loss per collision appears to be about $\frac{3}{4}$ ev, indicating typical ranges of several hundred angstroms. Below 25 ev energy, but not matter, propagates in the chain. At somewhat higher energies, the pulse assumes the character of a dynamic crowdion and produces an interstitial at its end.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Guest from Ordnance Materials Research Office.

G13. Configuration of the Vacancy and the Interstitial in Copper.* J. B. GIBSON, A. N. GOLAND,† M. MILGRAM, AND G. H. VINEYARD, *Brookhaven National Laboratory.*—The model discussed in the preceding abstracts has been used to investigate point defects in copper. Systems of 80 unit cells containing a defect in partially relaxed configuration are set up and given small initial velocities to eliminate symmetry. Because of damping, stable positions of atoms are eventually reached. Relaxations around a vacancy have been determined through eight shells of neighbors. Near neighbors relax inward about 5%, second and some higher neighbors move slightly outward. Results can be roughly fitted to the displacement field of a point singularity in a cubic elastic continuum, after approximations of Kröner. Contraction is about 0.4 atomic volumes. The isolated interstitial is not stable at the cube center in our model, but in a configuration (anticipated by Huntington) in which a lattice site is shared symmetrically with another atom, the pair having axis along ⟨100⟩ and separation 85% of normal near-neighbor distance. Formation energy is roughly 3 ev. A neighboring vacancy seems to stabilize the cube-center configuration of the interstitial.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Guest from Ordnance Materials Research Office.

G14. Ultrasonic Attenuation in Fast Neutron Irradiated Fused Silica at Low Temperature. R. E. STRAKNA, *U. S. Naval Ordnance Laboratory and University of Connecticut.*—Ultrasonic attenuation studies have been made in normal and fast neutron irradiated fused silica from 7 to 50 Mc/sec and from 1.5°K to 200°K using both longitudinal and shear

waves. The irradiated sample had been exposed to a total flux density greater than that required for maximum compacting of the structure. At all frequencies the internal friction was found to be approximately 20% less in the irradiated than in the normal sample. This differs from the anticipated change, which was a shift or change in shape of the absorption curve, based on a suggested Si-O-Si bond angle property of attenuation[1] and on bond angle changes due to irradiation found by x-ray diffraction studies.[2] From this work and from previous measurements[3] of changes of other physical properties with fast neutron irradiation, thermal spikes seem to be the "damaging" mechanism. A variation in the suggested structural dependence is proposed where now only those atoms near a structural defect can participate in the relaxation process. Thus, a decrease in the number of defects caused by local rearrangement in the thermal spike reduces the number of participating atoms.

[1] O. L. Anderson and H. E. Bömmel, J. Am. Ceram. Soc. **38**, 125 (1955).
[2] I. Simon, J. Am. Ceram. Soc. **40**, No. 5 (1957).
[3] W. Primak, Phys. Rev. **110**, 1240 (1958).

WEDNESDAY AFTERNOON AT 2:00

New Yorker Panel Room

(V. E. EATON presiding)

General Physics II

GA1. Asymmetry between the Two Lunar Faces. HUBERT REEVES, *Université de Montréal.*—It is proposed that the main agent responsible for the asymmetry between the two faces of the moon is possibly the scattering of the uncoming asteroids by the earth's gravitational field. The main uncertainty in the theory is the distribution $n(v_i)$ of the velocities (v_i) of asteroids with respect to the earth. If such a distribution falls off slower than v_i as v_i is decreased, then the theory is most likely to fit the bill. The theory predicts the same asymmetry for the incidence of small asteroids. Pictures of the moon with improved resolution should provide a test for the theory.

GA2. Structure of Pre-Supernovae Stars. HONG-YEE CHIU, *Institute for Advanced Study.*—Following Hoyle *et al.*[1] theory of collapse mechanism leading to a catastrophic implosion of a star, presumably leading to the occurrence of a supernovae, the structure of such stars has been formulated. We assume a core of density ρ around 10^7 g/cc and temperature T around 10^9 °K, surrounded by helium burning shells and other layers. We replace the structure of the star exterior to the core by suitable boundary conditions plus the composition from there outward. As the star evolves the core will gain in mass. When ρ is kept constant and we increase the temperature, the conversion of iron into helium will be completed in a narrow temperature range ($\sim 0.2\times 10^9$ °K), and the iron abundance function can be taken approximately as a step-down function of T. The transition temperature (corresponding to 50% iron abundance by weight) is a function of density and can be plotted in the ρ-T diagram. As the mass of the core increases, any point inside the core will describe a curve in the ρ-T diagram, called the *evolution track* of that point. When the point meets the 50% iron curve, it is forced to follow the 50% iron curve because the energy of conversion is 1.6×10^{18} ergs/g while at 8×10^9 °K the thermal energy is only 3×10^{17} ergs/g.

[1] Burbidge, Burbidge, Fowler, and Hoyle, Revs. Modern Phys. **29**, 547 (1957).

GA3. Diffusion of O_2 into X-Irradiated Lexan.* R. E. BARKER, JR.,† AND W. G. MOULTON, *University of Alabama.*—When Lexan, an aromatic polycarbonate, is irradiated with 40-kv x-rays, it changes in color from amber to green. A few hours after irradiation, the green color recedes from the sample edges with a sharp boundary between the green interior and amber edges. It has been demonstrated that this recession is caused by the destruction of the color centers by O_2 diffusion into the Lexan. This effect has been utilized to study the diffusion rate of O_2 in Lexan. The diffusion coefficient is found to obey an Arrhenius type relation with an activation energy of 7.2 kcal/mole and a frequency factor, D_0, of 2×10^4 mm²/day (±20%). Zener's[1] equation, $D_0=\gamma a^2\nu \exp(-\lambda E\beta/kT_m)$, relating diffusion to the thermal and mechanical characteristics, has been used to estimate an effective lattice constant, a. Taking the crystal structure factors, γ and λ, to be 1; β, a thermal coefficient of elasticity to be 0.1, and ν, T_m, and E/k to be respectively 10^{13} cps, 420°K, and 3600°K, the value of a is found to be 7 A. The optical absorption spectrum and the electron paramagnetic resonance spectrum have been examined in detail and the results have been correlated with the diffusion data.

* Supported by the U. S. Army Office of Ordnance Research.
† National Science Foundation Summer Teaching Fellow.
[1] C. Zener, J. Appl. Phys. **22**, 372 (1951).

GA4. Uniform Development of Thick Nuclear Emulsions Using a Wet Hot Stage.* D. KOTELCHUCK, *Cornell University.*—Thick emulsions, in which the grain density of plateau ionizing tracks does not vary with depth, have been obtained using a wet hot stage. This method gives grain density, fog density, and distortion measurements comparable to those obtained by standard temperature development techniques.[1] Uniformity is achieved by placing emulsions, already permeated with cold developer of a given pH, into a warming solution of slightly lower pH, thus somewhat retarding development near the top surface. For Ilford G5 600μ emulsions, the method is as follows: (all temperatures ~2°C unless otherwise noted) presoak 7 hours in distilled water; cold stage 2.5 hours in Amidol developer of pH 7.3; warm stage 1 hour at 25°C in warming solution of pH 6.6; fixing 1.5 clearing times; then the usual dilution, washing, and drying. The Amidol developer of pH 7.3 has the following composition: 3.0 g Amidol, 20.4 g Na_2SO_3, 0.87 g $NaHSO_3$, 8.0 ml 10% KBr solution, 1000 ml distilled water. The warming solution of pH 6.6 is: 6.8 g Na_2SO_3, 9.55 g $HaNSO_3$, 8.0 ml 10% KBr solution, 1000 ml distilled water.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and a National Science Foundation research grant.
[1] Dainton, Gattiker, and Lock, Phil. Mag. **42**, 396 (1951).

GA5. Angular Distribution of the Radiation Emitted by Electrons Accelerated in a Synchrotron.* J. A. RIGERT, D. E. BEDO, AND D. H. TOMBOULIAN, *Cornell University.*—It has already been pointed out[1] that the by-product radiation resulting from the operation of a synchrotron may serve as an

intense source for making measurements in the extreme ultraviolet or x-ray regions. Additional numerical calculations of the angular distribution of the radiation are presented for the case of a large accelerator such as the CEA. On the basis of classical theory,[2] the radiated power per unit angular interval per unit wavelength band at a fixed energy is evaluated as a function of the angle relative to the orbital plane for four different wavelengths in the region of intense radiation (0.1–100 A). The results are compared with those predicted by quantum theory.[3]

* Supported in part by the Office of Ordnance Research, U. S. Army.
[1] D. H. Tomboulian and D. E. Bedo, J. Appl. Phys. **29**, 804 (1958).
[2] J. Schwinger, Phys. Rev. **75**, 1912 (1949).
[3] H. Olsen, Kgl. Norske Videnskab. Selskabs, Forh. **No. 5**, (1952).

GA6. Barium Getter High-Vacuum Pump. P. J. EBERT, W. LIGNOS,* AND D. C. RALPH, *Louisiana State University.*—A high-vacuum pump utilizing barium[1] continuously evaporated has been constructed. The barium is evaporated from the liquid phase in an iron crucible and the rate of evaporation is controlled by the molecular effusion from a 2-mm aperture. The crucible is heated by radiation from a molybdenum heater[2] surrounded by three concentric heat shields. The effective surface receiving the barium is 150 in[2]. Pumping of inert gases is accomplished by a Penning discharge carrying a current of 100 μa at 5×10^{-6} mm Hg. Pumping speed for tank hydrogen is 500 l per sec from 10^{-4} to 10^{-6} mm Hg. Ultimate vacuum obtained is 3×10^{-7} mm Hg.

* NSF Teacher Research Participant, 1959. Now at Baton Rouge High School.
[1] Cloud, Beckman, and Trump, Rev. Sci. Instr. **28**, 889 (1957).
[2] E. V. Kornelsen and J. O. Weeks, Rev. Sci. Instr. **30**, 291 (1959).

GA7. Hydrocarbon Gas Evolution In Ion Pump Systems. DAVID LICHTMAN, *Sperry Gyroscope Company.*—An Omegatron mass spectrometer was used to analyze residual gases in a titanium cold cathode ion pump vacuum system. The existence of hydrocarbons in the mass spectrum verified reports of work done in other laboratories.[1] Considerable hydrocarbon gas evolution, predominantly methane, was found to occur when the ion pump was turned off. Experiments were performed to determine whether the source of the hydrocarbon gas was the ion pump or the hot filament of the mass spectrometer tube. The results of the experiments are given indicating the source to be the ion pump. The hydrocarbons are apparently formed at the titanium surface of the ion pump cathode. When the ion pump is turned off, the hydrocarbon gas partial pressure rises until an equilibrium condition exists between the hydrocarbon gas and the hydrocarbon adsorbed on the titanium surface. The quantity of hydrocarbon gas in an ion pumped system seems to depend on the quantity of gases containing hydrogen and carbon which was previously pumped.

[1] G. Reich, H. G. Noller, and E. Leybold, Cologne, Germany.

GA8. Vacuum Gauge for the Measurement of Pressures Down to 10^{-12} mm Hg. GEORGE BARNES, *University of Nevada.*—A new kind of vacuum gauge is described which should permit the measurement of vacuum pressures far below the lowest yet attained by man. The principle involved is the determination of true ion currents in an ionization gauge by measurement of the total light output when the ions strike a phosphor or scintillation crystal rather than by the direct measurement of the *net* ion collector current. The low pressure limitation of all present ionization type gauges, imposed by the photoemission of electrons from the ion collector by soft x-rays within the tube, is thus avoided.

GA9. Visibility of Luminous Objects through Fog in Absence and Presence of Search Lights.* MASAYUKI NAKAGAKI AND WILFRIED HELLER, *Wayne State University.*—The problem of visibility of luminous objects through fog was investigated on the basis of the Mie theory of radiation scattering by spheres assuming the fog to consist of spherical water droplets of relative refractive index 1.33. The two cases investigated are: (1) the luminous body consisting of or illuminated by a nearby light source is viewed through fog without search light; (2) it is viewed through fog with a search light, on the observer's side, directed towards the luminous body. The scattering functions available made it possible to consider fog droplets of any diameter up to 12 times the dimensions of the radiation wave length used. The three variables considered are: average droplet size, fog concentration, and wavelength. The conditions of optimum and minimum perception across a fog layer were established. One of the most interesting conclusions, tentatively arrived at previously[1] is that, within the visible range of radiation, yellow and red are, under certain conditions, far less suitable for fog penetration than green or blue.

* This work was carried out with the support of the Office of Naval Research.
[1] W. Heller, J. Chem. Phys. **23**, 342 (1955).

GA10. Simplicity Principle in the Composition of the Crystalline Matter of the Earth's Crust. N. EFREMOV, *600 West 142 Street, New York.*—Physico-chemical analysis of the composition of the crystalline matter of the earth's crust reveals a tendency to simplicity: 1. the mass of electronegative ions (mainly O^{2-}, S^{2-} etc) and that of electropositive ions in the composition of the earth's crust tend to achieve equilibrium (the relation 1:1). 2. The relation between the total mass of metals and the mass of silicon in the rocks constituting the earth's crust is that of simple small numbers. This is best illustrated by the compound known as the "kaolin kernel" —$Al_2Si_2O_7$ which is the basis of the most common and abundant rock-forming alumosilicates constituting the greatest part of the earth's crust. The kaolin kernel is characterized by almost ideal mass equilibrium not only between the mass of Al_2 (sum of atomic weights $26.97\times2=53.94$) and that of Si_2 (the sum of atomic weights $28.06\times2=56.12$), but also between the mass of electronegative ions (O_7) and the mass of electropositive ions (Al_2+Si_2). In both cases it approaches 1:1. Not only the composition of the earth's crust, but also that of stone meteorites follows the same principle of simplicity. Therefore, it seems that the formation and distribution of chemical elements must have been regulated by some thermoenergetic process of cosmic scope.

GA11. Carbon and Oxygen Isotope Fractionation in the Pyrolytic Decompositions of Some Metal Oxalates.* PETER E. YANKWICH AND PETROS D. ZAVITSANOS, *University of Illinois.*—Oxygen and carbon intramolecular isotope fractionation upon pyrolysis of some bivalent metal oxalates to carbon monoxide and carbon dioxide have been studied in parallel with the gross decomposition kinetics as an aid in establishing the molecular mechanism of the process. Intramolecular isotope effects at complete decomposition are of reasonable magnitude (0.5 to 1.0% near 500°K), exhibit normal temperature dependence, and reflect the mass of the metal ion; no oxygen isotope fractionation in carbon dioxide product is observed under any conditions. These observations are consistent with a molecular mechanism which is primarily oxygen atom transfer, as would be expected, no effects attributable to nucleation processes being observable. However, when attempts (as yet unsuccessful) were made to observe the intermolecular isotope fractionation at low degrees of reaction, it was discovered for manganous oxalate that the intramolecular carbon isotope effect exhibited strong "preparation"-dependence; the enormous sensitivity to temperature of these observations is strongly suggestive of their origin being physical rather than chemical.

* This research was supported by the U. S. Atomic Energy Commission.

GA12. Variational Theory of Chemical Reaction Rates Applied to Three-Body Recombination. JAMES C. KECK, *Avco-Everett Research Laboratory.*—A "variational" theory which gives a least upper bound to the rate of a chemical reaction is presented. The reaction is represented by the motion of a point in phase space across a "trial" surface dividing the "initial" and "final" chemical states. The "trial" surface is well defined in regions of phase space where interactions causing reaction are negligible, but is subject to arbitrary variations otherwise. It is shown that a least upper bound to the reaction rate can be obtained by calculating the rate at which representative points cross the "trail" surface, and then minimizing this rate with respect to allowed variations of the surface. Explicit calculations of the recombination rate of attracting atoms in the presence of repulsive third bodies are made for a simple "trial" surface having one adjustable parameter. At low temperatures the experimental rate constants are quite close to the theoretical bounds; at high temperatures the experimental data fall away from the bounds in a manner which can be understood in terms of various approximations contained in the theory. Promising methods of improving the agreement between theory and experiment are discussed.

WEDNESDAY AFTERNOON AT 2:00

New Yorker Boston Room

(H. FESHBACH presiding)

Theoretical Physics II: Nuclear Theory

H1. "Stripping" Type Process in Inelastic Scattering. DIPTI MITRA, *Saha Institute of Nuclear Physics, Calcutta,* AND MANOJ K. BANERJEE, *Princeton University.*—In the exchange process in inelastic scattering one may divide the interactions into two parts, (1) the interaction between exchanging particles, and (2) the interaction between the projectile and all the other nucleons of the target. The first type may be described as a "knockout" process and is the only type of exchange process which has been considered in theoretical calculations.[1] The second type describes a process analogous to the heavy particle stripping process and may, therefore, be termed as "stripping" type process. The nature of this term and the conditions under which it may be important has been discussed. It has been shown that the term is important at low energy and for light target nuclei, and that without the energy dependence of the optical potential the "stripping" type term would always be negligibly small. A comparison between the theoretical calculation and the experimental results of Braid and Yntema[2] in the case of the $C^{12}(p,p')C^{12*}(Q=4.45$ Mev, $E_p=10.8$ Mev) will be presented.

[1] C. A. Levinson and M. K. Banerjee, Ann. Phys. (N. Y.) **2**, 471 (1957).
[2] T. H. Braid and J. L. Yntema, Bull. Am. Phys. Soc. Ser. II, **4**, 17 (1959).

H2. Multichannel Resonance Reactions.* HARRY LUSTIG,† *University of Illinois.*—The formalism for the analysis of nuclear reactions in which, for each total angular momentum and parity, the effects of all but one resonance level are collected in a general term of the derivative matrix[1] is extended from the single channel case to that of an arbitrary number, N, of channels, The Blatt-Biedenharn scattering matrix[2] may then be conveniently expressed in terms of N partial widths, N "potential" phase shifts, and $\frac{1}{2}N(N-1)$ additional "potential" parameters. Total and differential cross sections may be readily expressed in terms of these parameters, and compared with experiments.

* Supported, in part, by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.
† On sabbatical leave from The City College of New York.
[1] Harry Lustig, Bull. Am. Phys. Soc. Ser. II, **3**, 368 (1958).
[2] J. M. Blatt and L. C. Biedenharn, Revs. Modern Phys. **24**, 258 (1952).

H3. On the Projection Theorem for the Energy Levels of Complex Nuclei.* SYUREI IWAO, *University of Rochester.*—The projection theorem for the energy levels of 2-1, 2-hole, 2-2, 3-1, 3-hole, 3-2, and 3-3 particle systems from the two particle system is derived assuming two-body forces in both the j-j and L-S coupling schemes. The theorem is applied to nuclei with mass number in the $A=30$ to 40 region. It predicts levels, spins, and parities of the nuclear states consistent with experiment. The even spin states belonging to the octuplet of $(f_{7/2})^2$ are predicted indirectly from the observed A^{40} levels and the theoretical predictions obtained from the A^{38}, Cl^{38} and Ca^{42} states taking all the possible spin assignments of the $J=4$ and 6 states of Ca^{42}. They are consistent with the recent experimental spin assignment of the Ca^{42} states by Morinaga *et al.* In getting the best fit, we have to assume that the seniorities of both the proton and the neutron group should be good quantum numbers which requires that the same spin, parity and different isotopic spin states of the space symmetric states in $(d_{3/2})^n$ and $(d_{5/2})^n$ have isotopic spin purity of $\sim$80%. The possible explanation of this big isotopic spin impurity is caused by the adjacent states with the same spin, parity, and the different isotopic spin of the spatially symmetric states.

* Supported in part by the U. S. Atomic Energy Commission.

H4. On Hyperfragments.* E. C. G. SUDARSHAN AND SYUREI IWAO, *University of Rochester* (introduced by R. E. Marshak).—All the light hyperfragments (including some unobserved ones) are systematically investigated using the so-called "Projection Theorem"[1] assuming two-body N-Λ forces in both L-S and j-j coupling for the hyperfragments with s-shell and p-shell nucleons respectively. The parameters of the two particle interactions in the s state derived from the $_{\Lambda}H^3$, $_{\Lambda}H^4(_{\Lambda}He^4)$ and $_{\Lambda}He^5$ binding energies show that only the antiparallel coupling of the nucleon group and the Λ spin is allowed for the ground states assuming that the spins of the nucleon groups do not change from those of their own ground states by the Λ binding. The mean kinetic energy of 8 Mev obtained for the Λ-particle in hyperfragments is consistent with the observed value of 7.5–8.7 mev. It is proved that the excited $J=1$ states of $_{\Lambda}H^4$ and $_{\Lambda}He^4$ are unbound by 0.20 and 0.68 mev, respectively; hence, the kaon is pseudoscalar relative to Λ as suggested from the $K^-+He^4 \rightarrow He^4+\pi^-$ reaction. The binding energy of the hyperfragments with p-shell nucleons requires two parameters for all the $A=6$ to 13 hyperfragments. The parameters determined to fit the binding energies of $_{\Lambda}Li^7$, $_{\Lambda}Li^8$, $_{\Lambda}Be^9$, and $_{\Lambda}Li^9$ explain these data within about 10% for the antiparallel and parallel couplings of the spin of the nucleon group and the Λ spin.

* Supported in part by the U. S. Atomic Energy Commission.
[1] See preceding abstract.

H5. Branching Ratios for the Decay of Nuclear Hyperfragments.* R. D. LAWSON, *Argonne National Laboratory*, AND MANUEL ROTENBERG, *University of Chicago.*—Calculations have been made to determine if the spin dependence of the Λ-nucleon force can be inferred from a study of the branching ratios for the π^- decay mode of hypernuclei. The probability of decay to the ground state of Be^7 (spin $\frac{3}{2}$) compared to the first excited state (spin $\frac{1}{2}$) depends on the spin of ${}_\Lambda Li^7$. Using *L-S* coupling for the nuclear states, one finds that if the spin of ${}_\Lambda Li^7$ is $\frac{3}{2}$ (indicating the triplet Λ-nucleon force is stronger), the above branching ratio is 1.2. Alternatively, if ${}_\Lambda Li^7$ has spin $\frac{1}{2}$ this ratio is 2.8, under the assumption that the parameters s and p in the decay interaction are equal. The same calculations have been carried out for the decay ${}_\Lambda B^{12} \rightarrow C^{12} + \pi^-$ by using the intermediate-coupling nuclear wave functions found by Kurath. The spin possibilities for the hypernucleus are 2 or 1, whereas the ground and first excited states of C^{12} have spin 0 and 2, respectively. In the case of ${}_\Lambda B^{12}$ decay the branching ratios are $(2 \rightarrow 2)/(2 \rightarrow 0) \cong 1.4$ and $(1 \rightarrow 2)/(1 \rightarrow 0) \cong 0.4$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

H6. Nuclear Correlation Functions from Inelastic Scattering. W. CZYZ,*† *Instytut Badan Jadrowych, Cracow*, AND K. GOTTFRIED,*† *Harvard University.*—It is well known that the cross section for scattering a weakly interacting probe (e.g. an electron) through momentum transfer q is related to the target's pair correlation function. We shall, however, discuss an experiment wherein not only q, but also the electron's energy loss ω is determined. The relevant cross section $\sigma(q,\omega)$ is then related to the time-dependent correlation function. If the target is a free Fermi gas, and q is held fixed, then $\sigma(q,\omega)=0$ for ω is greater than some critical value $\omega_c(q)$. We shall show that with only minor qualifications this property also obtains for finite targets such as heavy nuclei. If there are interactions between the target's constituents, then $\sigma(q,\omega)\neq 0$ for $\omega > \omega_c$: *for such values of ω the scattering is due entirely to correlations.* Calculations of $\sigma(q,\omega)$ in the domain of interest will be reported for simple models (e.g., the hard sphere gas), and the feasibility of gaining useful information about correlations in this fashion will be discussed.

* The greater part of this work was carried out at the Institute for Theoretical Physics, Copenhagen.
† Supported in part by the U. S. Air Force Office of Scientific Research.

H7. Collisions of Particles with Nuclei at Extremely High Energies.* R. J. GLAUBER, *Harvard University.*—If the incident particle has sufficiently high energy, an approximate solution of the general problem of multiple scattering may easily be effected in closed form. The optical potential which furnishes an equivalent description of the elastic scattering by a nucleus may be exhibited explicitly. It is conveniently discussed in terms of a pseudopotential which we may define to act between the incident particle and a target nucleon. The pseudopotential, apart from a constant factor, is the Fourier transform of the amplitude for elastic scattering by a single nucleon (with the momentum transfer as integration variable). It is in general complex and spin-dependent, and exists at arbitrarily high energies, whatever the underlying interaction. The optical potential for the nucleus, assuming the nucleons uncorrelated, is simply the average of the pseudopotential over the nuclear density distribution. The real and imaginary parts of the optical potential therefore, in general, differ slightly in shape. Since the range of the imaginary part of the pseudopotential is roughly half that of the real part, the imaginary part of the optical potential is a little more sharply defined than the real part. The effect of nucleon correlations also will be discussed.

* Supported in part by the U. S. Air Force Office of Scientific Research.

H8. Pair Correlations in Nuclei Determined from High-Energy Scattering. T. K. FOWLER, *Oak Ridge National Laboratory*,* AND K. M. WATSON, *University of California, Berkeley.*—The scattering of fast particles by atomic nuclei for large momentum transfers and small energy loss is studied. The cross sections may be expanded in inverse powers of the energy of the incident particle, using methods developed by Placzek and Wick. The resulting cross sections, when applied to analysis of experiments, may be used to study short range order in nuclei. An analysis of electron, pion, and proton experiments shows consistent results and also shows in a striking way the effects of the "repulsive core" in two body forces.

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

H9. $(d,p\gamma)$ Angular Correlations Predicted by the Distorted Wave Born Approximation. G. R. SATCHLER, *Oak Ridge National Laboratory* AND W. TOBOCMAN, *The Rice Institute.*—$(d,p\gamma)$ angular correlations have been calculated for several cases using four different forms of stripping theory: (a) plane wave Born approximation with cutoff (Butler theory), (b) Coulomb wave Born approximation with cutoff, (c) optical potential wave Born approximation with cutoff, (d) optical potential wave Born approximation without cutoff. The distortion effects are found to be strongly dependent on the direction of the emerging proton and on the type of distortion assumed. The fact that in a given case the (d,p) angular distribution is only slightly changed by distortion effects seems to be no guarantee that distortion effects on the $(d,p\gamma)$ angular correlation will be small. On the other hand, we have one case where distortion has an important effect on the angular distribution and a negligible effect on the angular correlation.

H10. Ground-State Properties of Nuclear Matter. R. D. PUFF AND P. C. MARTIN,* *Harvard University.*—The properties of nuclear matter in its ground state are studied by using Green's functions which take into account the bound nature of this state. An approximation is introduced to eliminate correlations of a single particle with a pair of particles when that pair is highly correlated. The approximation yields a set of equations for the energy, density, and energy-momentum distribution of the bound system. These equations define a single particle energy-momentum relation for the bound particles. On the other hand, the momentum distribution $\rho(k)$ differs from that of the noninteracting Fermi gas, since momenta larger than $k_f{}^p = (\frac{3}{2}\pi^2\rho)^{\frac{1}{3}}$ contribute significantly. The approximation exhibits a cut-off momentum about 10% larger than $k_f{}^p$. The calculated energy per particle is -14.9 mev, while the density is $(\frac{4}{3}\pi r_0{}^3)^{-1}$ with $r_0 = 0.92 \times 10^{-13}$ cm. In our approximation, the condition that the pressure vanish at equilibrium requires that the energy of the highest filled state, equal the average energy per particle. The single particle energy associated with the momentum $k_f{}^p$, which has no significance in our calculation since it is not the highest filled momentum state, is the same as the energy (~ -28 Mev) obtained by Brueckner for $k_f{}^p$. This coincidence suggests a qualitative explanation of the discrepancy between the highest single particle energy and the average energy per particle in his calculation.

* Supported in part by the U. S. Air Force Office of Scientific Research.

H11. Dispersion Theory of Direct Nuclear Reactions.* F. S. LEVIN, *University of Maryland.*—Nuclear reactions have been studied as particular cases of rearrangement collisions, neglecting Coulomb forces. The transition matrix, $T_{\beta\alpha}$, taken between plane wave states and from which the interactions have been eliminated contains both resonant and nonresonant terms. The latter are evaluated at the nuclear surface and are

interpreted as direct interaction amplitudes. Interference effects between the resonant and direct interaction amplitudes are present in the differential cross section, but not the total cross section because of the optical theorem. For the case of S-wave scattering by a potential well, the total cross section has the form deduced by Kapur and Peierls, implying that in the plane wave case the direct interaction terms are generalizations of the potential scattering terms of the S-wave problem. Antisymmetrization has been carried out in nucleon-nucleus and deuteron stripping reactions and contributes to both the resonant and nonresonant amplitudes. Application to some specific reactions will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.

H12. Optical Potential Including the Pauli Principle.* M. H. MITTLEMAN, *Lawrence Radiation Laboratory, Livermore.*—An exact reduction of the problem of the scattering of a fermion by a bound system of identical fermions to a one body problem of the scattering in an optical potential will be presented. The point of view taken is that the bound system wave functions are exactly known (not necessarily Hartree-Fock), and that the optical potential is to be generated from them. Previous derivations have assumed that the bound system could be described by Hartree-Fock wave functions[1] or have taken the point of view that the wave functions of the bound system are to be determined by an expansion,[2] which is carried out simultaneously with a similar expansion of the optical potential, i.e., a linked diagram expansion. For the example of the scattering of an electron by atomic helium, our method seems to be superior. Its drawbacks will be discussed.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Lippman, Mittleman, and Watson, Phys. Rev. (to be published).
[2] L. M. Franz and R. L. Mills (to be published); J. S. Bell and E. J. Squires, Phys. Rev. Letters **3**, 96 (1959).

H13. One-Pion Exchange and the Optical Model.* BERNARD A. LIPPMANN AND MICHAEL J. MORAVCSIK, *Lawrence Radiation Laboratory, Livermore.*—The successful application of the one-pion exchange contribution to the analysis of nucleon-nucleon scattering[1] suggests that similar methods might be used to predict nucleon-nucleus scattering. We have tested this idea by deriving an optical potential from the one-pion exchange scattering amplitude. Since this scattering amplitude is purely real, the optical theorem was used to provide the optical potential with an imaginary part; a "reasonable" spin-orbit term was also added. In general, our results fit the experimental data on differential cross section and polarization quite well in the range 50–100 Mev and less well elsewhere. The fit in the region up to 50 Mev can be improved if the amplitude given by effective range theory is substituted for the S-wave part of the one-pion exchange scattering amplitude.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] Cziffra, MacGregor, Moravcsik, and Stapp, Phys. Rev. **114**, 880 (1959).

H14. Nuclear Forces and the Properties of Nuclear Matter.* S. A. MOSZKOWSKI AND B. L. SCOTT, *University of California, Los Angeles.*—The application of the Brueckner theory to the nuclear many-body problem can be greatly simplified if one separates the two-nucleon interactions (for any given state and relative momentum) into a short-range part v_s and a long-range part v_l. The cut is made such that v_s alone gives no phase shift for free particle scattering. If the separation is made in this way, then the presence of nuclear matter as manifested by the Pauli principle has only a small effect on the two particle wave function at short distances. On the other hand, the Pauli principle drastically reduces the induced correlations due to v_l. In fact, v_l is the first approximation to the effective interaction in nuclear matter. This procedure permits one to expand systematically the effective interaction in terms of v_l and t_s, the reaction operator for free particles caused by v_s alone. The contribution of all first- and second-order terms to the binding energy of extended nuclear matter has been calculated numerically. The results strongly indicate that this series converges rapidly, in agreement with the physical arguments above. Thus, an accurate value for the density and binding energy of extended nuclear matter may be obtained.

* This work was supported in part by the Office of Ordnance Research.

WEDNESDAY AFTERNOON AT 2:00

Hotel Astor, North Ballroom

(J. M. BURGERS presiding)

Joint Session of the Division of Fluid Dynamics and the Institute of Aeronautical Sciences

HA1. Boundary Layer Transition at Subsonic Speeds. ITIRO TANI, *University of Tokyo, Japan.* (30 min.)

HA2. Viscous Flow Past a Quarter Infinite Plate. K. STEWARTSON, *University of Durham, England.* (30 min.)

HA3. Theoretical Results on Three-Dimensional Hypersonic Flow. P. GERMAIN, *Université de Paris, France.* (30 min.)

HA4. Demographic Method in Rarefied Gas Dynamics. MICHAŁ ŁUNC, *Polish Academy of Sciences, Warsaw, Poland.* (30 min.)

WEDNESDAY AFTERNOON AT 4:45

New Yorker Grand Ballroom

(G. E. UHLENBECK presiding)

Business Meeting of The American Physical Society

THURSDAY MORNING AT 9:30

New Yorker Empire Suite

(HENRY SEMAT presiding)

HB. Post-deadline papers, if any

THURSDAY MORNING AT 9:30

Statler-Hilton Penn Top South

(B. N. BROCKHOUSE presiding)

Neutron Physics III

I1. Study of Gamma-Ray Spectra From Neutron Resonances in Platinum using Digital Magnetic Tape Recording. J. R. WATERS* AND J. R. BIRD, *AERE, Harwell, England.*—The high energy gamma-ray spectra resulting from resonant neutron capture in platinum have been investigated for neutron energies up to 600 ev. The Harwell 15-Mev electron linear accelerator was used as a pulsed neutron source. Neutron capture in the platinum target was detected by observing the pulses from a 4 in.×4 in. NaI(Tl) detector. Sixty-three channels of gamma-ray energy and 255 of neutron time of flight were recorded simultaneously as binary numbers across 1-in. wide magnetic tape giving a total of 16 000 possible combinations. These define the gamma-ray spectra for the resonances and the background in between them. By analyzing the data on the tapes a three dimensional plot of neutron time of flight *vs* gamma-ray energy *vs* counts was obtained. The 47-, 68.5-, and 98-ev resonances give spectra for neutron capture in Pt^{192}, Pt^{196}, and Pt^{198}. The intensity of the ground-state transition for capture in Pt^{195} showed large fluctuations from resonance to resonance.

* Now at Rensselaer Polytechnic Institute, Troy, New York.

I2. Neutron Resonances in Gold and Niobium.* S. DESJARDINS, J. L. ROSEN, JAMES RAINWATER, AND W. W. HAVENS, JR., *Columbia University.*—The Columbia University Nevis Velocity Selector has been used to measure neutron resonances in gold and niobium. The measurements employed neutron capture self-detection as well as a B^{10}-NaI flat detector. The detector gate widths were 0.1 μsec and a flight path of 35.37 meters was used. Results of analysis for niobium indicate the *s*- and *p*-wave strength functions to be $(0.35\pm0.10)\times10^{-4}$ and $(6\pm2)\times10^{-4}$, respectively. The method of extracting these quantities will be discussed. While the value of the *p*-wave strength function agrees with those obtained by measurements of average cross sections in the kev region, the *s*-wave strength function is found to be ∼ three times the previously quoted value, and is in better agreement with measurements for neighboring values of A. The values of $\bar{\Gamma}_\gamma$ obtained for both of these elements indicate that they should be taken some 30% to 50% larger than the commonly accepted values. The gold *s*-wave strength function is 1.2×10^{-4} in excellent agreement with the work of others. Spin assignments for several of the larger levels in gold have been made.

* This work was partially supported by the U. S. Atomic Energy Commission.

I3. Neutron Giant Resonances. A Nuclear Ramsauer Effect.* J. M. PETERSON, *Lawrence Radiation Laboratory, Livermore.*—The surface formed by a three-dimensional plot of neutron total cross section *versus* neutron energy *versus* mass number shows three families of broad maxima called neutron "giant resonances." All the data can be successfully analyzed in terms of an optical model. Feshbach, Porter, and Weisskopf attributed the maxima to single-particle resonances; Lane, Wigner, and Thomas extended this interpretation. The argument here concerns only the interpretation of the experimental and optical model results and questions that the single-particle resonance interpretation is valid because (a) the energy-mass number dependence of the maxima, (b) the absence of corresponding maxima in the nonelastic cross sections, and (c) the changing structure of partial waves within a family of maxima are inconsistent with this interpretation. However, a simple picture, suggested by Mottelson and Glassgold, does explain all the salient features of the giant resonances. It focuses attention on the interference of the neutron wave traversing the nucleus with that going around (analogous to the electron Ramsauer effect). Simple calculations predict three (and only three) families of maxima corresponding to relative phases of π, 3π, and 5π, whose positions agree with experiment.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

I4. Determination of the *J* Values of *s*-Type Neutron Resonances by Multiple Scattering. A. W. SÁENZ AND S. PODGOR, *U. S. Naval Research Laboratory.*—The dependence of the multiple scattering of neutrons by isolated *s*-type resonances with $\Gamma_n/\Gamma\approx1$ on the values $I\pm\frac{1}{2}$ of J has been studied by the Monte Carlo method. We have coded for the NAREC the problem of neutrons of energy E_i incident normally on a flat plate of thickness t composed of nuclei with such a resonance, neglecting Doppler corrections, but allowing for arbitrary polarization f_n and f_N of the incident beam and target, respectively. The ratio r of the reflected neutrons to those emerging from the front face (scattered and unscattered) is slowly varying in Γ and Γ_n/Γ for the cases of moderately thick targets treated. As an example of our results for $f_n=f_N=0$, the most interesting case experimentally, we find for the 132-ev resonance of Co^{59}, using $\Gamma=5.0$ ev, $\Gamma_n/\Gamma=0.90$, $E_i=132$ ev, and $t=2$ in units of the nominal cross section $2\pi\lambda_0^2(\Gamma_n/\Gamma)^2$, that $r=1.16$, 1.54 for $J=3$, 4, respectively, tabulating 10 000 histories for each J. This and similar results indicate that, in principle, the measurement of r or of analogous ratios for $f_n=f_N=0$ determines J for a number of scattering resonances of the type considered here.

I5. Gamma Rays from Capture of Neutrons in U^{235}.* M. K. BRUSSEL, D. J. HUGHES, AND R. L. ZIMMERMAN, *Brookhaven National Laboratory.*—In a continuation of work investigating radiative transition probabilities from neutron excited

resonances, we have measured the gamma-ray spectrum near 4.06 Mev in U^{239} for different neutron resonances. From thermal neutron capture studies with a pair spectrometer, Campion *et al.*[1] have observed a strong gamma ray peak near E_γ equal to 4.062 Mev well-separated from a weaker transition at 3.662 Mev. Work at Brookhaven, using thermal neutrons, and resonant neutron work at Chalk River, with the Brookhaven fast chopper, has resolved this 4.06-Mev peak using NaI(Tl) crystal detection. Preliminary analysis has shown that the gross spectra from resonance to resonance are very similar. At the 4.06-Mev peak relative gamma-ray transition probability measurements have been made for resonances up to a neutron energy of approximately 200 ev. For ten resonances, we find that the average deviation from the mean for these transition probabilities is approximately 20%.

* Work carried out under the auspices of the U. S. Atomic Energy Commission.
[1] Campion, Knowles, Manning, and Bartholomew, Can. J. Phys. **37**, 377 (1959).

I6. An Absolute Determination of the Total Neutron Cross Sections of U^{233} and U^{235}.* G. J. SAFFORD, B. M. RUSTAD, AND W. W. HAVENS, JR., *Columbia University and Brookhaven National Laboratory.*—Absolute values of the total neutron cross sections of U^{233} and U^{235} were measured with the Columbia University Neutron Crystal spectrometer over the neutron energy range from 0.000818 ev to 0.0818 ev. Two types of samples, metallic foils and D_2O solutions of uranium nitrate, were used to obtain the cross sections for each isotope. Balanced solutions of $UO_2(NO_3)_2$ were used to determine the differences between the total cross sections of U^{233} and U^{238} and of U^{235} and U^{238}. These values when combined with the relatively small known values of the total cross sections for U^{238} give $\sigma_T(U^{233}) = 587 \pm 5$ barns and $\sigma_T(U^{235}) = 695 \pm 2$ barns at 2200 m/sec. The measurements on the metallic foils agreed with the results from the nitrate solutions to better than 1% yielding $\sigma_T(U^{233}) = 586 \pm 2$ barns and $\sigma_T(U^{235}) = 698.7 \pm 4.7$ barns at 2200 m/sec.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

I7. Resonance Energy Neutron Cross Section of U^{233}. N. J. PATTENDEN,* J. A. HARVEY, A. CULKOWSKI, AND N. DISMUKE, *Oak Ridge National Laboratory.*—The Oak Ridge National Laboratory neutron chopper[1] has been used to measure the total cross section of U^{233} in the neutron energy range 0.1 to 100 ev. The measurements were made on highly enriched metal foils (99.76% U^{233}) of thicknesses down to 0.005 in. In the region below 23 ev, 23 levels were observed. The data obtained at lower energies have been considered together with the fission cross section and η measurements of Fluharty *et al.*[2] to obtain parameters of the resonances. Comparisons were made between the data and theoretical cross sections calculated on an IBM 704 computer, using the multilevel, multichannel method of Vogt.[3]

* On leave from Atomic Energy Research Establishment, Harwell, England.
[1] Block, Harvey, and Slaughter, Bull. Am. Phys. Soc. Ser. II, **4**, 270 (1959).
[2] Fluharty, Moore, and Evans, *Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958* (United Nations, Geneva, 1959), Vol. 15, p. 111.
[3] E. Vogt, Phys. Rev. **112**, 203 (1958); Bull. Am. Phys. Soc. Ser. II, **4**, 271 (1959).

I8. Delayed Neutrons per Fission for 14-Mev Neutron Induced Fission of U^{235} and U^{238}.* W. I. MCGARRY, R. J. OMOHUNDRO, AND G. E. HOLLOWAY, *U. S. Naval Research Laboratory* (introduced by L. A. Beach).—Using disks of 93% enriched U^{235} and depleted U^{238}, measurements of (n/f), the number of delayed neutrons per fission, for fission induced by 14-Mev neutrons have been experimentally determined. Values of $(n/f) = 0.022 \pm 0.005$ for U^{235} and 0.066 ± 0.017 for U^{238} have been obtained. Values of (n/f) for other isotopes will be reported and compared with theoretical predictions, and other experimental measurements.[1,2]

* Research supported by the U. S. Atomic Energy Commission.
[1] G. R. Keepin, J. Nuclear Energy **7**, 29 (1958).
[2] K. H. Sun *et al.*, Phys. Rev. **79**, 3 (1950).

I9. Ratio of Asymmetric to Symmetric Fission of Pu^{239} and of Pu^{241} as a Function of Neutron Energy.* R. B. REGIER, W. H. BURGUS, AND B. H. SORENSEN, *Phillips Petroleum Company, Idaho Falls* (introduced by J. E. Evans).—The theoretical prediction[1] that in neutron-induced fission the ratio of asymmetric to symmetric fission may differ between the two possible spin states was earlier tested[2] with U^{233} at the MTR. This work has now been extended to Pu^{239} and Pu^{241}. Fission of the Pu isotopes was studied as a function of neutron energy with thermal, *epi*-Sm, and crystal spectrometer monoenergetic neutrons. The radiochemically determined ratios of Mo^{99}/Cd^{115}, Mo^{99}/Sn^{121}, and Mo^{99}/Sn^{125} were found to be about three times as large at the 0.297-ev Pu^{239} resonance as at thermal energies. The difference in mass ratios can be shown to be at least a factor of 5 between the two different spin states in this energy region, if it is assumed that spin difference is the principal cause of change in the ratio of asymmetric to symmetric fission. This effect in Pu^{239} is the largest observed to date. In the case of Pu^{241}, the ratio for *epi*-Sm neutron fission was found essentially equal to that for thermal fission.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] J. A. Wheeler, Physica **22**, 1103 (1956).
[2] Regier, Burgus, and Tromp, Phys. Rev. **113**, 1589 (1959).

I10. Neutron Spectra of Pu-Be and Cf^{252} Measured by a New High-Efficiency Method.* H. W. BROEK† AND C. E. ANDERSON, *Yale University.*—The neutron spectra of Pu-Be and Cf^{252} have been measured and agreement with previous work is obtained. The Pu-Be measurement definitely confirms a peak at 9.7 Mev that was suggested by previous data. Calculation indicates that such a peak should indeed exist. The spectra were obtained by analysis of scintillations produced in a stilbene crystal by recoil protons from *n-p* scattering. Discimination against gamma rays and electrons is accomplished by utilizing differences in the rate of emission of light produced by electrons and protons.

* This work was supported by the U. S. Atomic Energy Commission.
† N.S.F. Cooperative Graduate Fellow, 1959–1960.

I11. Variation of η of U^{233} with Energy. G. G. SLAUGHTER AND J. A. HARVEY, *Oak Ridge National Laboratory.*—The ORNL Fast Chopper was utilized in determining the variation of η of U^{233} with energy using the direct measurement technique.[1] The U^{233} sample was in the form of four metallic foils each 1½ in. by 3 in. by 0.025 in. consisting of 99.76% U^{233} with 0.022% U^{234} and 0.21% U^{238}. Simultaneous measurements of the number of fission neutrons from the sample and the incident neutrons were made as a function of incident neutron energy. The number of neutrons absorbed was calculated from the measured transmission of the sample and the theoretical effective scattering. The value of η was normalized to 2.30[2] at thermal, and the measurement extended to 3 ev in overlapping ranges, encompassing resonances at 0.16 ev, 1.45 ev, 1.76 ev, and 2.30 ev. The measurements are being continued to higher energies.

[1] Palevsky, Hughes, Zimmerman, and Eisberg, J. Nuclear Energy **3**, 177 (1956).
[2] Macklin, deSaussure, Kington, and Lyon, Bull. Am. Phys. Soc. Ser. II, **4**, 414 (1959).

I12. Ranges in Air of Fragments From Spontaneous Fission of Cf^{252}.* JOHN A. MISKEL AND K. V. MARSH, *University of California, Livermore.*—Mean and extrapolated ranges in air have been determined for a number of Cf^{252} fission fragments.

Individual fission products were isolated, by radio-chemical techniques, from each of a series of thin plastic foils spaced uniformly along the fragment path. Differential range curves were obtained from these data and extrapolated ranges determined by integration of the differential curves. A comparison of the mass vs range curve was made with a similar curve for neutron induced fission of Pu^{239}.[1]

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Katcoff, Miskel, and Stanley, Phys. Rev. 74, 631 (1948).

THURSDAY MORNING AT 9:30

New Yorker Boston Room

(H. PRIMAKOFF presiding)

Theoretical Physics III: Nuclear Theory

IA1. Nucleon Reduced Widths and Charge Independence.* WILLIAM M. MACDONALD AND JERRY B. MARION, *University of Maryland.*—A new criterion (called the *isotopic spin addition* rule) is established for the comparison of nucleon reduced widths of $T=1$ levels in isobaric triads. The rule is shown to be essentially independent of any isotopic spin impurity in the $M_T=0$ level. This criterion has been used in a reanalysis of the mirror levels at 8.89 Mev in B^{10} and 7.37 Mev in Be^{10}. If equivalent square well (ESW) radii are used to compute the penetrabilities for the neutrons and protons, it is found that the isotopic spin addition rule can be satisfied only if an ESW radius for the proton interaction is taken to be approximately 1f larger than the ESW radius for the neutron interaction. It is pointed out that this result is in qualitative agreement with current models of nuclear potential wells.

* Supported in part by the U. S. Atomic Energy Commission.

IA2. Photodisintegration of ^3H and ^3He. L. M. DELVES, *Oxford University, England* (introduced by R. J. Blin-Stoyle).—At low energies the photodisintegration cross sections of ^3H and ^3He can be expressed in terms of the effective range parameters for neutron-deuteron scattering. The predicted cross sections for the two possible sets of scattering lengths are very different; this allows an unambiguous determination of the correct set.

IA3. Elastic Scattering of Deuterons. WILLIAM S. PORTER, *Bucknell University.*—The elastic scattering of 4.07-Mev deuterons by several elements[1] has been analyzed using the sharp cutoff model of Blair. This is of interest since the validity of the optical model for deuteron scattering is uncertain. It was found that cutoff values of the orbital angular momentum of between 4 and 6 were necessary to explain the observed cross sections. For these nuclei, rather large values of the deuteron-target interaction radius are thereby implied. It may be that electric disintegration of the deuteron is important here as it is believed to be for scattering by heavier elements.[2]

[1] I. Slaus and W. Parker Alford, Phys. Rev. 114, 1054 (1959).
[2] Nishida, Progr. Theoret. Phys. (Kyoto) 19, 389 (1958).

IA4. Upper Bound on the Neutron-Deuteron Doublet Scattering Length.* LARRY SPRUCH AND LEONARD ROSENBERG, *New York University.*—The method of obtaining upper bounds on scattering lengths is applied to the determination of the *n-d* doublet scattering length, A_D. A new calculation is unnecessary; an analysis of the trial function used by Efimov in a variational estimate of A_D shows that that calculation effectively provides a bound. Thus $A_D \leq 1.1$ fermis. If the potentials used by Efimov are accurate, it follows that of the two experimentally allowed sets, namely, $A_D=0.7$ f and $A_Q=6.2$ f (Set I), or $A_D=8.3$ f and $A_Q=2.6$ f (Set II), Set I is correct, a conclusion consistent with some recent variational estimates of about 6 f for A_Q. It is also shown that, more generally, the exact (numerically determined) value of the "static" scattering length lies above the true value if the number of bound state solutions for the static and true problems is the same. This result applies, in particular, to the present problem, although the Efimov calculation (where polarization is included) gives a better estimate of A_D.

* Sponsored by both the Geophysics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command, and the Office of Ordnance Research, U. S. Army.

IA5. Inelastic Rotational Scattering in the Adiabatic Approximation.* J. S. BLAIR, D. SHARP,† AND L. WILETS, *University of Washington.*—Spheroidal wave functions have been employed in generalizing the sharp cutoff approximation to obtain the scattering amplitude from a black absorbing spheroid including terms first order in the deformation. The Coulomb potential can be included to the same order. From the amplitude the inelastic scattering cross section for excitation of the first 2+ state of an even-even nucleus is obtained in the adiabatic approximation. Elastic and inelastic differential cross sections have been computed numerically for neutral projectiles for values of the cutoff angular momentum through 40. At forward angles the cross sections approach those obtained using the Fraunhofer approximation. For all but backward angles the oscillations in the elastic and inelastic angular distributions are out of phase with one another. The envelopes of both elastic and inelastic cross sections increase as the scattering angle approaches 180° and the oscillations come into phase. Comparison will be made to alpha particle scattering experiments.

* Supported in part by the U. S. Atomic Energy Commission.
† Summer visitor, presently at Princeton University, Princeton, New Jersey.

IA6. Phenomenological Nuclear Potentials from Neutron Scattering from O^{16}. E. G. CORMAN* AND J. L. FOWLER, *Oak Ridge National Laboratory.*—The bound state information on O^{17}, and neutron scattering from O^{16}, allows one to construct phenomenological nuclear potentials which describe the single particle states of O^{17}.[1] With the Woods-Saxon form of this potential, $V(r)=-V_0/[1+\exp(r-R/A)]$, the parameters which fit O^{17} are: $A=0.50$, and $R=3.32$ fermis. For the $2s$ state and s phase shifts, $V_0=50.7$ Mev. With a Thomas spin-orbit energy term, multiplied by $\gamma=19.0$, the $1d$ states and the d phase shifts are given with $V_0=47.5$ Mev. If the velocity dependence of the potential is included by use of the reduced mass formalism, $m=m_0/[1+KV(r)]^2$; and if $m=0.5m_0$ at $r=0$, the $2s$ state and the $d_{\frac{3}{2}}$ state are described by the following parameters: $A=0.50$ f, $R=2.55$ f, $V_0=121.7$ Mev, and $\gamma=10.8$. With these parameters the bound $d_{\frac{3}{2}}$ state, however, comes too low in energy, (~ -8.5 Mev). Other values

of K are being tried. These calculations are carried out with a digital high speed computer.

* Summer Visitor at ORNL during 1959. Now at the University of Kansas, Lawrence, Kansas.
[1] J. L. Fowler and H. O. Cohn, Phys. Rev. **109**, 89 (1958).
[2] Ross, Lawson, and Mark, Phys. Rev. **104**, 401 (1956).

IA7. High-Energy Potential Scattering.* B. C. CARLSON AND F. J. LYNCH, *Iowa State University.*—The amplitude for scattering of a Schrödinger particle by a static potential was written by Saxon and Schiff[1] in an exact form that reduces to the stationary-phase approximations of Schiff when the energy is high and the scattering angle is sufficiently small or sufficiently large. The Saxon-Schiff amplitude has been derived in an alternative way that has some advantage in simplicity. The amplitude is obtained in a form characteristic of scattering by two potentials; in the present instance one potential is associated with forward scattering. The two-potential form of the amplitude is shown to be exactly equivalent to the Saxon-Schiff form.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] D. S. Saxon and L. I. Schiff, Nuovo cimento **6**, 614 (1957).

IA8. Spin-Orbit Coupling for Spin-One Particles. G. R. SATCHLER, *Oak Ridge National Laboratory.*—A one-body spin-orbit potential for spin-1 particles may contain, in addition to the familiar vector term $\mathbf{l}\cdot\mathbf{s}$ used with spin-$\frac{1}{2}$ particles, certain tensor terms T. T is a scalar product of second rank spherical tensors, $T=\mathbf{R}_2\cdot\mathbf{S}_2$, where $\mathbf{S}_2$ operates in the spin space of the particle and $\mathbf{R}_2$ in coordinate space. $\mathbf{S}_2$ is uniquely determined, but several forms of $\mathbf{R}_2$ may be constructed from the position vector $\mathbf{r}$, momentum vector $\mathbf{p}$, and orbital angular momentum vector $\mathbf{l}$. The requirements of time reversal invariance and parity conservation limit these to three. If a complex potential is allowed, as in the optical model for scattering from nuclei, time reversal invariance may be relaxed and another form of $\mathbf{R}_2$ becomes allowed. Only one of these forms of T remains diagonal in the orbital angular momentum l. The implications for the scattering and polarization of spin one particles will be discussed, with particular reference to deuterons.

IA9. Exchange Nature of the Three-Body Vector Force in Nuclei. ARNOLD M. FEINGOLD, *University of Utah.*—Second-order effects of the tensor force are known to give doublet splittings of the right sign and magnitude required by the shell model.[1] This splitting may be ascribed to an effective vector force which is predominantly of a three-body type.[2] However, the three-body vector force derived in this manner from the empirical two-body tensor force has the wrong exchange character to fit the experimental data.[3] The explicit second-order calculations of Teresawa[1] show that this defect lies in a closure approximation which overemphasizes the role of high lying states. A simple modification of the derivation of the three-body vector force, consisting of replacing the Majorana exchange operator by unity *before* applying closure, gives a three-body vector force that fits the experimental doublet splittings in various light nuclei remarkably well. Justification for this revised form of the effective vector force will be given.

[1] T. Teresawa, Progr. Theoret. Phys. (Kyoto) **22**, 150 (1959); B. Jancovici (to be published); A. M. Feingold, Phys. Rev. **101**, 258 (1956).
[2] A. M. Feingold, Phys. Rev. **105**, 944 (1957).
[3] A. M. Feingold, Phys. Rev. **114**, 540 (1959).

IA10. Semi-Phenomenological Proton-Proton Potential.* R. A. BRYAN, *University of Rochester* (introduced by R. E. Marshak).—The greatly improved fit to the high energy p-p scattering data achieved by the Signell-Marshak and the Gammel-Thayler potential models has prompted further work to utilize the best features of both approaches. In the spirit of the SM model, we have employed static and spin-orbit potentials with the correct meson-theoretic asymptotic forms. In the region where the two-pion contribution is dominant for the static potential, we have retained the characteristic shapes as calculated by TMO, KMO, and Gartenhaus, but, as in the GT approach, we have fixed the potential in the middle region by closely fitting the 310-Mev MMS[2] phase shift solution 1 for p-p scattering. The spin-orbit potential in the middle region has been obtained purely phenomenologically. Repulsive cores are employed in the inner region. The resulting p-p potential model represents a substantial improvement over previous models in the 40–310-Mev region.

* Supported in part by the IBM Corporation and the U. S. Atomic Energy Commission.
[1] Konuma, Miyazawa, and Otsuki, Progr. Theoret. Phys. (Kyoto) **9**, 17 (1958).
[2] MacGregor, M. J. Moravcsik, and Stapp, "Modified analysis of nucleon-nucleon scattering II. Completed analysis of p-p scattering at 310 Mev" (UCRL-5566, May 1, 1959).

IA11. Solution of Integral Equation for the Static Nuclear Force.* WILLIAM FRANK, *U. S. Naval Ordnance Laboratory,* AND ARNOLD TUBIS, *Worcester Polytechnic Institute.*—An integral equation, derived by Chew-Low methods,[1] for the exact static nuclear potential is studied. A method is presented for deriving the successive terms of an asymptotic expansion of the nuclear potential. Several of the existing potentials are derived from different approximations to the solution. The leading term of the asymptotic expansion is the familiar one-meson exchange potential. The next term differs from the TMO and Miyazawa fourth-order potentials. The results will be discussed.

* Work done jointly at Brookhaven National Laboratory.
[1] W. Frank, Ann. Phys. (N. Y.) (to be published).

IA12. Pseudoscalar Interaction in β Decay. C. P. BHALLA* AND M. E. ROSE, *Oak Ridge National Laboratory.*—The experiments on allowed beta transitions which, during the past two years, have provided a virtually unique interpretation of the β interaction, shed no light on the question of the possibility of a pseudoscalar contribution. In order to determine whether such a contribution is really needed, an examination of $0\rightarrow 0$ (yes) transitions has been made. The only experimental criteria which are relevant here are the spectrum shape and the longitudinal polarization of the beta particles. Using the form of the pseudoscalar interaction which results from the Foldy-Wouthuysen transformation the polarization resulting from the A-P mixture has been calculated. Numerical results will depend on the ratio of two nuclear matrix elements as well as on the ratio of P to A coupling constants. Taking into account the finite size of the nucleus, an analysis of the Pr^{144} data will be presented. The assumptions made are: time reversal invariance for the strong as well as for the weak interactions is valid and the two component theory of the neutrino is used.

* Oak Ridge Institute of Nuclear Studies Graduate Fellow.

IA13. Bremsstrahlung in 150-Mev p-p Collisions.* C. DULLEMOND, J. J. DE SWART, AND R. E. MARSHAK, *University of Rochester.*—Calculations of the cross section for bremsstrahlung in 150-Mev p-p collisions have been carried out. We considered only the high energy end of the γ-ray spectrum where the final state of the protons is a singlet S state. The multipole radiation of lowest order is $E2$ radiation which occurs when a transition takes place from the $^1D_2$ to the $^1S_0$ state. Calculations were done for this transition assuming the validity of the Siegert theorem and neglecting the Coulomb interaction between the protons. The SM potential was used for the initial state.[1] For the final state we used a square-well potential with a hard core whose depth and range were adjusted to give the correct effective range and scattering

length. The cross section reaches a peak very close to the maximum γ-ray energy and decreases rapidly toward lower γ-ray energies. The width of the peak is about 1 Mev, while the peak value of the cross section was calculated to be $d\sigma/dE_\gamma = 0.03$-μbarn Mev^{-1}. Information about p-p bremsstrahlung in the high-energy region of the photon spectrum could therefore shed light on the potentials in the singlet even states of the nucleon-nucleon system.

* Supported in part by the U. S. Atomic Energy Commission.
[1] P. S. Signell and R. E. Marshak, Phys. Rev. **109**, 1229 (1958).

THURSDAY MORNING AT 9:30

Statler-Hilton Ivy Suite

(LYLE BORST presiding)

General Nuclear Physics

J1. Masses of Ne^{18} and Si^{26}.* F. AJZENBERG-SELOVE, *Haverford College*, AND K. L. DUNNING, *Naval Research Laboratory*.—A thin target of magnesium oxide, enriched to 100% Mg^{24}, deposited on a tantalum backing,[1] was bombarded by 5.52-Mev He^3 particles. Ilford C-2 emulsions were exposed at ten angles to the incident beam.[2] Measurements at 0° and 135° of the proton recoil spectra form the $O^{16}(He^3,n)Ne^{18}$ and $Mg^{24}(He^3,n)Si^{26}$ reactions indicate that the Q value of the first reaction is -3.20 ± 0.05 Mev and that therefore the $(M-A)$ of $Ne^{18} = 10.65\pm0.05$ Mev. This is in excellent agreement with a value of 10.656 ± 0.015 Mev obtained in a neutron threshold experiment.[3] The Q-value of the reaction leading to the ground state of Si^{26} is 0.13 ± 0.08 Mev: $(M-A) = 0.47\pm0.09$ Mev. Less energetic groups of neutrons are also observed to excited states of Si^{26} at 1.8, 2.8 and (3.4) Mev. These results will be discussed in terms of the level structure of the $A=26$ isobaric triad.

* Research supported by the National Science Foundation, and the Office of Naval Research.
[1] The target was supplied by the Atomic Energy Research Establishment, Harwell, England.
[2] We are indebted to R. O. Bondelid and A. Lemonick for their assistance in the exposure of the plates.
[3] K. L. Dunning and J. W. Butler, Bull. Am. Phys. Soc. Ser. II, **4**, 444 (1959).

J2. Experimental Limits for the Proton-Electron Charge Difference and for the Neutron Charge.* J. C. ZORN, G. E. CHAMBERLAIN, AND V. W. HUGHES, *Yale University*.—Because of the recent interest[1] in the questions of the equality of the electron and proton charges and of the neutrality of the neutron,[2] upper limits to the charges of CsF and KF molecules have been measured by observing the deflection of a molecular beam in a homogeneous electric field.[3] The results are: $|q(\mathrm{CsF})| \leq 2\times10^{-14}|q_e|$, and $|q(\mathrm{KF})| \leq 1\times10^{-13}|q_e|$, where q_e is the electron charge. If the molecular charge is assumed to be $Z\delta q + Nq_n$, where Z is the number of protons, $\delta q \equiv q_p + q_e$, q_p is the proton charge, N is the number of neutrons and q_n is the neutron charge, then $|\delta q| \leq 1.7\times10^{-14}|q_e|$ and, independently, $|q_n| \leq 1.3\times10^{-14}|q_e|$. If one assumes that $\delta q = q_n$, then $|\delta q| \leq 1.3\times10^{-13}|q_e|$.

* This research has been supported in part by the National Aeronautics and Space Administration and by the Research Corporation.
[1] R. Lyttleton and H. Bondi, Proc. Roy. Soc. (London) **A252**, 313 (1959); G. Feinberg and M. Goldhaber, paper delivered before the National Academy of Sciences on April 29, 1959 (unpublished).
[2] I. Shapiro and V. Estulin, Soviet Phys. JETP **3**, 626 (1957).
[3] V. W. Hughes, Phys. Rev. **105**, 170 (1957).

J3. Experimental Confirmation of Line Shape Theory.* L. Y. CHOW, V. W. HUGHES, AND J. A. WHITE, *Yale University*.—For a transition induced between two energy levels in an atomic beam experiment, the line shape as a function of the amplitude of the oscillating field has been calculated by Torrey and Salwen[1] under the assumption that the atom is subjected to an oscillating field which is constant in amplitude and phase throughout the transition region. The magnetic field insensitive transition[2] between the hyperfine levels $(F,m_F) = (\frac{3}{2}, -\frac{1}{2})$ and $(\frac{1}{2}, -\frac{1}{2})$ of the metastable $^3S_1$ state of He^3 at the field of 802.5 gauss which corresponds to the minimum transition frequency of 6354.2513 Mc/sec has been chosen here to check the line shape theory. The constant amplitude and phase of the rf in the transition region have been achieved by use of a rectangular cavity operating in the TE_{101} mode. The measured values of line intensity and line width as a function of the rf amplitude agree with the theoretical values within the experimental errors of about 10%. The highest rf amplitude used is about 12 times the value which corresponds to the maximum transition probability.

* This research has been supported in part by the Air Force Office of Scientific Research.
[1] P. Kusch and V. W. Hughes, *Encyclopedia of Physics* (Springer-Verlag, Berlin, Germany, 1959), Vol. 37/1.
[2] White, Chow, Drake, and Hughes "Hyperfine structure of the metastable $^3S_1$ state of He^3," Phys. Rev. Letters (to be published).

J4. Widths of Monoenergetic Gamma Lines from the Annihilation-in-Flight of Positrons.* S. C. FULTZ, C. P. JUPITER, C. R. HATCHER, AND F. D. SEWARD, *Lawrence Radiation Laboratory, Livermore*.—Using an improved geometry, an examination of photon spectra arising from the annihilation-in-flight of positrons of chosen momenta has been made by use of a total-absorption gamma spectrometer. Thick NaI(Tl) crystals, 4×5 in. in diameter and 6×5 in. in diameter, were used in the spectrometer. For each chosen momentum, background and electron bremsstrahlung measurements were made. From these it was possible to separate the positron bremsstrahlung, scattered bremsstrahlung, and neutron backgrounds, from the spectra of the annihilation photons. Widths of the gamma lines could then be found by use of the crystal response functions. By using a 0.5-Mev thick Be target, line widths at half-maximum of about 0.6 Mev were obtained, which included the positron momentum interval. Yields of photons in terms of electron current will be given. An examination of the cross sections for the annihilation-in-flight of positrons of several energies has been made.

* Work done under the auspices of the U. S. Atomic Energy Commission.

J5. Monoenergetic Photons from the Annihilation-in-Flight of Positrons.* C. P. JUPITER, N. E. HANSEN, H. W. KOCH,† AND S. C. FULTZ, *Lawrence Radiation Laboratory, Livermore*.—The Livermore electron linear accelerator has been used as a source of positrons by having 20-Mev electrons bombard a thick tantalum target. For a particular geometry used, a calculation has been made of the yield of annihilation photons in the forward direction, as detected by a 4×5 in. diam NaI(Tl) crystal spectrometer. Yields of the bremsstrahlung and positrons created in the thick tantalum target were calculated by use of the Bethe-Heitler integrated-over-angle

cross section equations, while the number of 10-Mev annihilation photons created was deduced from the Dirac differential cross section equation converted to the laboratory system. The results of preliminary measurements are in reasonable agreement with calculation.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† On leave from National Bureau of Standards.

J6. Free Positron Annihilation in Liquid Helium and Positron Scattering in Helium.* HARISH C. KHARE AND P. R. WALLACE, *McGill University.*—The positron lifetime in liquid helium as observed by Graham and Paul[1] is $(1.83\pm0.15)\times10^{-9}$ sec at 4.2°K and one atmos. The theoretical calculations, taking into account the polarization of helium, give the lifetime as 7.0×10^{-9} sec, for a positron of zero energy. This value is four times longer than the observed value. Calculations of lifetime as a function of positron energy leads to agreement at 5 ev. This leads one to suspect that the positron is not thermalized before annihilation, as assumed until now. The scattering cross section and phase shift for average positron energy of 18 ev is $0.4\pi a_0^2$ and -0.32, respectively. Teutsch and Hughes[2] have calculated the cross sections for elastic scattering from an indirect experiment and obtained the value of $0.023\pi a_0^2$; which is far too small. The possibility that these discrepancies can be resolved by the existence of a bound or quasi-bound state of positron and helium atom will be discussed.

* Work supported by The National Research Council, Canada.
[1] R. L. Graham and D. A. L. Paul, Bull. Am. Phys. Soc. Ser. II, 2, 38, (1957).
[2] W. B. Teutsch and V. W. Hughes, Phys. Rev. 10, 1266 (1956).

J7. Proposal for Detecting the Polarization of Slow Protrons.* JUERGEN HEBERLE, *Argonne National Laboratory.*—It has been shown recently[1] that it is possible to detect metastable hydrogen atoms formed from 10-kev protons moving through a gas. If the proton polarization is P, the fractional populations of the hyperfine components ($F=1$, $m_F=+1$), (1,0), (1, −1), and (0,0) of the $2^2S_{\frac{1}{2}}$ state are $(1+P)/4$, $\frac{1}{4}$, $(1-P)/4$, and $\frac{1}{4}$, respectively. The differences between these populations can be revealed by means of (1) magnetic analysis[2] alone, (2) magnetic resonance[2] together with magnetic analysis, or (3) magnetic resonance with rf state selection.[3] The approximate determination of P in each of these cases will be discussed. These methods should be useful for testing the various proposed sources of polarized protons.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] L. Madansky and G. E. Owen, Phys. Rev. Letters, 2, 209 (1959).
[2] Heberle, Reich, and Kusch, Phys. Rev. 101, 612 (1956).
[3] R. Novick and E. D. Commins, Phys. Rev. 111, 822 (1958).

J8. Perturbation Theory for an Accelerator with a General Magnetic Field.* GEORGE PARZEN,† *Midwestern Universities Research Association.*—The problem of finding the effect of a perturbing field in an accelerator with a general magnetic field has been investigated. The perturbing field assumed should cover such cases as straight sections, steering magnets, and other deliberate perturbations that may be introduced. Expressions have been found for the effect of the perturbing field on the equilibrium orbit and betatron oscillations of the accelerator. The approximations made will be discussed, and results of the theory for some special cases will be compared with numerically computed results.

* Supported by the U. S. Atomic Energy Commission.
† On leave from the University of Notre Dame.

J9. Effects of a Field Bump on the 3/3 Nonlinear Resonance. M. M. GORDON, *Michigan State University.*—As part of the M.S.U. cyclotron program, a study is being carried out on the problem of beam extraction from a three-sector medium energy cyclotron. The mechanism for the extraction process consists of a correlation of the effects of the $\nu_r=3/3$ resonance and a "$\cos\theta$" field bump. Analytical and computer calculations have been carried out to evaluate these effects. The phase plots associated with the 3/3 resonance in the absence of a field bump are characterized by three inner unstable fixed points, and three outer stable fixed points.[1] The effects of a field bump on the structure of these phase plots depend on the azimuthal location of the bump and on the value of ν_r. One, and sometimes two corners of the central stability triangle open up such that some phase points flow outward and loop around the outer stable fixed points. In general, as the strength of the bump increases, pairs of fixed points move toward each other, coalesce, and disappear.

[1] P. A. Sturrock, Ann. Phys. (N. Y.) 3, 113 (1958); L. J. Laslett and S. J. Wolfson, MURA-497 (1959).

J10. Accidental Coincidence Monitoring System. K. W. MARLOW, *Naval Research Laboratory.*—A system will be described for monitoring the accidental coincidence count rate during the course of a measurement of coincidences.[1] Such a monitor is very important where singles count rates vary widely during the counting interval, with the result that a separate measurement with fixed delay is inaccurate or not feasible. The system utilizes two pulses from each detector; a prompt pulse followed by another pulse delayed by a fixed amount of time. The two pulses from each detector are mixed at the input to the coincidence circuit. The coincidence circuit puts out two pulses for each real (or accidental) event which occurs within the resolution of the coincidence circuit. Purely accidental coincidences are also typified by a single pulse from the coincidence circuit. Associated circuits (consisting primarily of flip-flops) are able to differentiate between the "single" and "double" pulses, and to supply pulses to two different scalers, one recording real pulse accidental coincidences and the other recording twice the number of accidental counts.

[1] The basic idea for this system was proposed by Tor Ragnar Gerholm (private communication).

J11. Scintillation Response of Activated Inorganic Crystals to Various Charged Particles. A. MEYER AND R. B. MURRAY, *Oak Ridge National Laboratory.*—Experimental studies of the response of inorganic scintillation crystals, as NaI(Tl), to various charged particles indicate decreasing scintillation efficiency with increasing particle mass, and a nonlinearity in pulse-height *vs* energy for heavier particles. This work presents a calculation based on a model of the process of energy-transfer from the incoming particle to the activator sites. The model assumes that the particle produces, per cm, a number of energy carriers (electrons or excitons) which is proportional to dE/dx. The migration of carriers to activator sites is described by a diffusion equation, in which the density of available activator sites is treated as a variable. The depletion of available activator sites by a particle with high dE/dx accounts for so-called "saturation effects." Results of this calculation, plotted as relative pulse-height *vs* energy for various particles, are in accord with experiment. Effects dependent on activator concentration are also predicted. Comparison of this calculation with experiment yields a value for the diffusion length of the energy carrier of order 30 A. This model is not applied to incident electrons, and thus does not account for their anomalously low scintillation efficiency.

J12. Bubble Nucleation in Liquid Hydrogen Bubble Chambers.* V. P. KENNEY, *Brookhaven National Laboratory and the University of Kentucky.*—The bubble densities of the tracks of 635 Mev/c protons and pions in a 6-in. liquid hydrogen bubble chamber, operated at 26.5°K, 62 psig, have been determined

from measurements of the distribution in spacing of the individual bubbles. The velocity dependence of the bubble density is of the form $m=A/\beta^b$, where a least-squares fit to the data gives $A=4.32$ bubbles/mm and exponent $b=1.934 \pm 0.077$. The constant A is a function of temperature, varying $\sim 30\%$ per 0.1°K. Assuming that the number of bubbles per unit track length observed is correlated with the number of δ rays per unit track length having energies between the minimum needed for bubble nucleation and a maximum corresponding to a range which is twice the critical bubble radius $r=2\sigma/\Delta P$,[1] the present data indicate that an energy of the order of 400 ev is required to produce a bubble in liquid hydrogen.

* Work performed under the auspices of the U. S. Atomic Energy Commission, supported in part by the National Science Foundation.
[1] D. V. Bugg (to be published).

J13. Response of Surface-Barrier Semiconductor Counters to N^{14} Ions. M. L. HALBERT, J. L. BLANKENSHIP, AND M. V. GOLDMAN,* *Oak Ridge National Laboratory.*†—The response of a germanium surface-barrier counter at 77°K and of a silicon counter at room temperature was measured for N^{14} ions from the 63-in. cyclotron. For the Si counter, the ratio R of pulse height to particle energy is constant from 15 to 25 Mev within experimental error ($\lesssim 1\%$). These data were obtained by detecting N^{14} elastically scattered from Al^{27} at various angles. Other data were obtained for both counters by degrading the beam energy with absorbers. Within the accuracy with which the energy loss in the absorbers is known, R=constant from 3 to 24 Mev. The ratio of N^{14} to Po^{210} α-particle pulse height equals their energy ratio for both Ge and Si. Stability is excellent. The N^{14} peak position varied less than $\frac{1}{2}\%$ over a 5-day period. No shift with counting rate was observed. The resolution for the scattered N^{14} is $\sim 2\%$. Probably most of this spread is due to target nonuniformity, beam-energy spread, etc., since the resolution for 5.3 Mev α-particles is considerably better. The energy loss per ion pair is about 25% greater in Si than in Ge.

* Summer employee from Princeton University.
† Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.

J14. Semiconductor Surface Barrier Counters of Improved Energy Resolution. J. L. BLANKENSHIP AND C. J. BORKOWSKI, *Oak Ridge National Laboratory.**—Gold silicon surface barrier counters which operate satisfactorily at room temperature have been reported previously.[1] Silicon counters exhibit good energy resolution and pulse height-energy linearity if the alpha range does not exceed the barrier depletion region. Counters made from 50 ohm-cm material require at least 18 v bias for a 5.3 Mev alpha particle, but counters made from 150 ohm-cm material require only $4\frac{1}{2}$ v bias. The energy resolution of a 5 mm×5 mm counter made from 50 ohm-cm material operating at room temperature was 45–50 kev (0.9%) full width at half-height for Po^{210} (5.3 Mev) alpha particles. Germanium surface barrier counters similar to those previously reported[2,3] except operated at dry-ice temperatures, have given good energy resolution. A 4 mm×4 mm counter made from 15 ohm-cm germanium gave a resolution of 1.2% for U^{233} (4.82 Mev) alphas, using a bias of 6 v.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.
[1] J. M. McKenzie and D. A. Bromley, Bull. Am. Phys. Soc. Ser. II, 4, 422 (1959).
[2] J. M. McKenzie and D. A. Bromley, Phys. Rev. Letters 2, 303 (1959).
[3] F. J. Walter *et al.*, ORNL Report CF 58-11-99 (1958), (unpublished).

J15. Behavior of Semiconductor Counters. F. J. WALTER, J. W. T. DABBS, AND L. D. ROBERTS, *Oak Ridge National Laboratory.*—Semiconductor surface barrier counters with fast rise times, good energy resolution, and nearly linear energy response to short-range charged particles have been described previously.[1,2] A simple model[3] based on a Schottky-type barrier is proposed to explain their behavior. This model predicts a maximum output voltage pulse corresponding to the charge liberated by ionizing radiation divided by the Schottky capacitance of the barrier. Higher purity of the semiconducting material corresponds to a thicker barrier, and thus to a larger output pulse. Minimum pulse rise time is obtained when the barrier thickness just exceeds the particle range. For n-type germanium counters, measurements of pulse heights, effective capacitances, and pulse rise times as functions of applied bias and sample purity are in agreement with this model, provided the bulk resistivity of the crystal is relatively low. However, at very low temperatures where the resistivity of germanium is large, the experimental evidence indicates that significant potential gradients can exist across the whole crystal rather than only in the narrow barrier region.

[1] Walter, Dabbs, and Roberts, Bull. Am. Phys. Soc. Ser. II, 3, 181 (1958).
[2] J. M. McKenzie and D. A. Bromley, Bull. Am. Phys. Soc. Ser. II, 4, 422 (1959).
[3] F. J. Walter *et al.*, ORNL Report CF-58-11-59 (1958) (unpublished).

THURSDAY MORNING AT 9:45

Statler Hilton Grand Ballroom

(CONYERS HERRING presiding)

Symposium of the Division of Solid State Physics
Quantum-Mechanical Tunneling in Solids

JA1. Tunneling in Semiconductor Junctions. P. J. PRICE, *International Business Machines Corporation.* (40 min.)

JA2. Experimental Confirmation of the Tunneling Laws in Semiconductor Junctions. A. G. CHYNOWETH, *Bell Telephone Laboratories.* (30 min.)

JA3. Direct and Phonon-Assisted Tunneling in Germanium and Silicon Junctions. R. N. HALL, *General Electric Research Laboratory.* (30 min.)

Invited Paper

JA4. New Approach to the Theory of Superexchange Interactions. P. W. ANDERSON, *Bell Telephone Laboratories.* (30 min.)

THURSDAY MORNING AT 9:15

New Yorker Panel Room

(HARVEY BROOKS presiding)

Mechanical Properties of Solids

K1. Lattice Vibrations in Lead. I. T. ARASE, B. N. BROCKHOUSE, G. CAGLIOTI, AND A. D. B. WOODS, *Chalk River Laboratories.*—Dispersion relations of the lattice vibrations in the symmetric directions, $[\zeta,0,0]$, $[\zeta,\zeta,0]$, and $[\zeta,\zeta,\zeta]$, of a Pb single crystal at 100°K have been obtained by the methods of neutron spectrometry. The frequencies of some special phonons (units 10^{12} c/s) are $T[1,0,0]=0.92\pm0.03$, $L[1,0,0]=1.95\pm0.05$, $T[\frac{1}{2},\frac{1}{2},\frac{1}{2}]=0.90\pm0.03$, $L[\frac{1}{2},\frac{1}{2},\frac{1}{2}]=2.14\pm0.05$. The results for small ζ are consistent with the rather poorly known elastic constants. It is of interest that the dispersion relations in the $[\zeta,0,0]$ direction have local *minima* at the zone boundary. There are thus several extra critical points in the frequency distribution of lead. The dispersion curves have been Fourier analyzed to yield interplanar force constants, as suggested by Foreman and Lomer. The results indicate that the interionic forces in lead extend to at least fifth, and probably still more distant, neighbors. Measurements in the three symmetric directions (regardless of their accuracy) do not contain sufficient information to enable solution of the general fifth neighbor problem. We are therefore making measurements in the symmetric $[1,\zeta,0]$ direction, and at general positions in reciprocal space. The measurements will be utilized to try to obtain a definite force constant model.

K2. Lattice Vibrations in Lead. II. B. N. BROCKHOUSE, G. CAGLIOTI,* M. SAKAMOTO,† R. N. SINCLAIR,‡ AND A. D. B. WOODS, *Chalk River Laboratories.*—The frequency-wave number ($\nu(\mathbf{q})$) dispersion relation of the lattice vibrations in the $[\zeta,0,0]$ and $[\zeta,\zeta,\zeta]$ directions of a lead crystal have been measured by neutron spectrometry at several temperatures up to 425°K. At the higher temperatures neutron groups corresponding to vibrations of fairly high $\mathbf{q}$ were considerably energy broadened. The amount of broadening increased with increasing temperature, perhaps a little faster than linearly, and varied considerably from one vibration to another. The line shape was approximately Lorentzian. At 425°K the full width at half-maximum (ΔE) averaged about $\frac{1}{4}$ of the phonon energy $h\nu$. If energy widths are identified with phonon lifetimes (τ) by the uncertainty relation $\tau\Delta E=2\hbar$, then the lifetimes at 435°K are ~1.3 vibrational periods. Thus the lifetimes extrapolated to the melting temperature are about one vibrational period. Accepting the centers of the broadened groups as giving phonon frequencies, we have calculated interplanar force constants. The force constants between nearest planes decrease slowly with increasing temperature. Force constants between more distant planes decrease more rapidly, suggesting that the range of the interionic forces in lead decreases with increasing temperature.

* Visiting Scientist from Comitato Nazionale Ricerche Nucleari, Rome.
† Visiting Scientist from the Japan Atomic Energy Research Institute.
‡ National Research Council of Canada post-doctorate fellow.

K3. Multiple Phonon Emission by Neutrons. MARK NELKIN, AND DONALD E. PARKS, *General Atomic.*—The scattering and resonant absorption of neutrons by the nuclei in a crystal are considered in the case that the recoil energy, R, is large compared to $\bar{E}$, the kinetic energy per atom associated with the lattice vibrations. Under these conditions the average number of phonons emitted in a single collision is large, and one can make use of a "short collision time"approximation of the type introduced by Wick.[1] The explicit expansion used by Wick gives singular expressions for differential quantities such as the energy transfer cross section $\sigma(E_0,E,\theta)$ for inelastic scattering, and the Doppler broadened line, shape $W(E)$ for absorption. A somewhat modified expansion is introduced in the present work which corresponds exactly, in the case of a system of harmonic oscillators, to the use of the central limit theorem of probability theory. (The results apply to an arbitrary system by a rearrangement of the terms in Wick's expansion, but the relation to the central limit theorem only applies to a crystal.) The expression obtained can therefore be shown rigorously to be an asymptotic expansion in $(\bar{E}/R)^{\frac{1}{2}}$. The leading term in the case of the absorption resonance is the "weak binding" limit introduced by Lamb.

[1] G. C. Wick, Phys. Rev. **94**, 1228 (1954).

K4. Acoustic Absorption by Phonon-Phonon Interaction. W. P. RANEY, H. E. BÖMMEL, and K. DRANSFELD, *Bell Telephone Laboratories.*—Bömmel and Dransfeld[1] recently proposed a mechanism for the interaction of sound waves with the thermal phonons to explain the observed hypersonic absorption in crystalline quartz. The coefficient of absorption α depends on specific heat C, temperature T, a properly defined average Grüneisen constant γ_{kr}, density ρ, sound velocity V, angular frequency ω and a phonon-phonon relaxation time τ:

$$\alpha=1.1\frac{C\cdot T\cdot\gamma_{kr}^2}{\rho\cdot V^3}\left(\frac{\omega^2\tau}{1+(\omega\tau)^2}\right).$$

This mechanism should, of course, not be restricted to quartz. Evidence will be presented, based on recent data by Dobbs *et al.*[2] and the authors, that the same mechanism is also present in Germanium. The observed fact that in Ge, shear waves are much less attenuated than longitudinal waves is in agreement with γ_{kr} values deduced from unpublished data by Mason and McSkimin on the second order elastic constants in Ge.

[1] H. E. Bömmel and K. Dransfeld, Bull. Am. Phys. Soc. Ser. II, **4**, 226 (1959).
[2] Dobbs, Chick, and Truell, Phys. Rev. Letters **3**, 332 (1959).

K5. Amplitude and Temperature Dependence of the Attenuation of 40 kc Sound in Aluminum. T. S. HUTCHISON AND D. H. ROGERS, *Royal Military College.*—A year ago[1] we reported measurements on a sample of 99.995% pure aluminum, and the failure of the measurements to agree precisely with predictions of the theory of Granato and Lücke.[2] The reason advanced at that time for this disagreement has proved to be in error. The theory of Granato and Lücke has been examined and extended. The results of new measurements on another specimen of aluminum, as well as those of the former specimen, seem adequately described by a theory of the Granato and Lücke type, where the portions of the attenuation due to the dynamic losses and break-away losses of the screw dislocations in the specimen are both found to be amplitude dependent, and of comparable magnitude, in some circumstances, to the normal Granato and Lücke type edge dislocation losses. The effect of thermal activation on these processes will be discussed and compared with the aluminum measurements.

[1] Rogers, Filmer, and Hutchison, Bull. Am. Phys. Soc. Ser. II, **4**, 47 (1959).
[2] A. Granato and K. Lücke, J. Appl. Phys. **27**, 583, 789 (1956).

K6. Temperature Dependence of Bragg Peaks and Vibration Spectra. ANTHONY J. KENNEDY, *Carnegie Institute of Technology*, AND PAUL M. MARCUS, *I.B.M. Research Center, Poughkeepsie.*—The temperature-dependent factor for the integrated intensity of x-ray diffraction peaks, the Debye-Waller factor, is expressible in terms of the lattice spectrum alone for cubic lattices, but is independent of normal mode polarization directions. Hence this factor may be precisely expressed in terms of an equivalent Debye-Waller theta, $\theta_{DW}(T)$, defined at each temperature, T, as if the spectrum were Debye. Low and high T expansions of $\theta_{DW}(T)$ are obtained for general lattice spectra with arbitrary anisotropy and dispersion, and related to corresponding expansions of the specific heat Debye theta. The limiting expression holds to rather low T. Exact calculations of $\theta_{DW}(T)$ for all T(0°K to 800°K) have been made for Al using two spectrum models, one with correct anisotropy of sound velocities, and correct numbers of all models, but no dispersion, and one which introduces in addition a standard amount of dispersion. *Measured* elastic constants and lattice spacings are used at all T. The results bracket the measurements of Chipman, indicating less dispersion in the real spectrum than was assumed. The measurements determine the minus second moment of the spectrum; comparison with values obtained from the specific heat, a force constant model, and spectra obtained by diffuse x-ray and neutron scattering shows moderate agreement.

K7. Elastic Constants of V, Nb, and Ta. D. I. BOLEF AND M. MENES, *Westinghouse Research Laboratories.*—The room temperature elastic constants of single crystals of vanadium, niobium, and tantalum have been measured. Measurements were made on [110] and [100] oriented crystals using ultrasonic pulse techniques and a cw resonance technique at 10 mc and 30 mc. A correction factor for end effects due to the transducer was applied to the measured values. The elastic constants, obtained in units of 10^{11} dynes/cm², are

	C_{11}	C_{44}	C_{12}
V	22.9	4.38	11.7
Nb	19.2	5.68	13.4
Ta	26.5	8.31	15.9

X-ray values of densities were used to obtain these constants from the measured sound velocities. The bulk moduli obtained for V and Ta agree to within 2% with those measured by Bridgman.[1] The elastic constants of vanadium agree closely with unpublished results of G. A. Alers. One of the Ta single crystals was generously supplied by A. Calverley.

[1] P. Bridgman, *Physics at High Pressures* (G. Bell and Sons, London, England, 1952).

K8. Elastic Constants of CsBr, CsI, RbBr, and RbI.* K. REINITZ AND H. B. HUNTINGTON, *Rensselaer Polytechnic Institute.*—The elastic constants of CsBr and CsI specimens obtained from Harshaw Chemical Co. were determined ultrasonically as a function of temperature from 300°K to 73°K. Room temperature constants of RbBr and RbI samples procured from Dr. K. Korth of the Kiel Physical Laboratory were also measured. The values of C_{11}, C_{12}, and C_{44} in units of 10^{11} dynes/cm² at 22°C for these salts are:

	C_{11}	C_{12}	C_{44}
CsBr	3.097	0.903	0.7500
CsI	2.434	0.636	0.6316
RbBr	3.15	0.493	0.384
RbI	2.54	0.407	0.276

An ultrasonic interferometer similar to the one constructed by Williams and Lamb[1] was used to measure the sound velocities in the cesium salts at 10 Mc. The temperature dependence of the elastic constants was determined, while the samples warmed up at the rate of 0.3°C/min, and was found to be negative in all cases and nearly linear over the temperature range investigated. The values of the rubidium salt constants compare favorably with the values found by Bergmann, and also by Spangenberg, and Haussuhl.[2]

* Supported by the Office of Ordnance Research, U. S. Army, and the National Science Foundation.

[1] J. Williams and J. Lamb, J. Acoust. Soc. Am. **30**, 308–313 (1958).

[2] L. Bergmann, Z. Naturforsch. **12a**, 229–233 (1957); K. Spangenberg and S. Haussuhl, Z. Krist **109**, 422–437 (1957).

K9. Positive Temperature Coefficient of Young's Modulus of Vitreous Germania. S. SPINNER AND G. W. CLEEK, *National Bureau of Standards* (introduced by A. D. Franklin).—The temperature dependence of Young's modulus of vitreous GeO_2 has been determined by a dynamic resonance method. The coefficient was found to be positive from room temperature to about 400°C. The only other glass known to have a positive temperature coefficient of elastic modulus is vitreous SiO_2. In view of the similarity in structure and bond energies of these two materials,* the agreement in this anomalous positive coefficient of elastic modulus is believed to be significant. This similarity in one anharmonic property, temperature coefficient of elastic modulus, contrasts with the large disagreement in another other commonly measured anharmonic property, thermal expansion.

* J. D. Mackenzie, J. Am. Ceram. Soc. **42**, [6], 310 (1959).

K10. Thermal Variation of the Elastic Constants of Fused Silica. RICHARD F. WEEKS, *Richard D. Brew and Company, Incorporated.*—The elastic constants of fused silica and their thermal coefficients have been calculated from measurements of the velocity of propagation of 15 mc signals. The use of large samples and the May technique[1] of time measurement yield standard deviations of 0.05% in the velocity figures. Poisson's ratio and its thermal coefficient were determined from the coefficient of thermal expansion and the ratio of the travel times of compressional and shear signals in the temperature range between −50° and 100°C. Young's modulus and its thermal coefficient were calculated from the signal velocity, Poisson's ratio, and published value of the density of fused silica. The advantages of this type of calculation are discussed. The parameters determined in this way agree well with previous ultrasonic measurements, but differ significantly from the values obtained with static and audio frequency techniques. The elastic parameters of two samples exhibiting entirely different internal strain patterns were identical which indicates that the perturbation in the elastic parameters due to strain are averaged out in these measurements. A simple model is proposed which qualitatively explains the relationships between the thermal coefficients of the elastic parameters of fused silica.

[1] J. E. May, 1958 Institute of Radio Engineers National Convention Record, p. 134.

K11. Surface Elastic Waves in Cubic Crystals. DENOS C. GAZIS, AND ROBERT HERMAN, *General Motors Corporation*, AND RICHARD F. WALLIS, *U. S. Naval Research Laboratory.*—A theoretical investigation of surface elastic waves in cubic crystals, using a theory developed by Stoneley, has been carried out. The range of elastic constants for which Rayleigh type surface waves exist on a (100) free surface has been determined. For other allowed values of the elastic constants, generalized Rayleigh waves exist which are characterized by complex attenuation constants. In the latter case certain directions of propagation parallel to the surface may be excluded. A lattice dynamical theory of surface waves has been developed for a monatomic simple cubic lattice with nearest, and next nearest neighbor central forces, and angle-bending forces involving successive nearest neighbors. The surface waves exhibit dispersion when the wavelength is comparable to the lattice spacing. In the case of Rayleigh waves a critical wavelength exists, in general, such that for shorter wavelengths the atomic displacements show a reversal in phase between successive layers parallel to the surface.

K12. Low-Temperature Stress Relaxation Peaks in Plastically Deformed Polycrystalline Niobium.* R. H. CHAMBERS, AND J. SCHULTZ.†—Peaks in acoustical energy absorption for frequencies in the ten's of kilocycles have been observed at 10°K and 165°K in plastically deformed commercially pure polycrystalline niobium. Rod-shaped specimens were prestrained in tension at room temperature in varying amounts from 1 to 10%. Internal friction measurements were made over a temperature range from 4°K to 300°K by a resonant bar technique employing alternating longitudinal stress at *ca.* 20 kc. A marked dependence of the relaxation strength (peak heights) on amount of prestrain was observed for the 165°K peak. The peak hieght increases rapidly with increasing prestrain up to 3% extension; thereafter it slowly decreases with further increase in prestrain. High-vacuum anneal at 210°C for 25 min eliminates both peaks and simultaneously increases by tenfold the alternating strain amplitude necessary to produce nonlinear resonant behavior. The relaxation peaks are discussed in terms of intrinsic dislocation relaxation; and the annealing phenomenon, in terms of the pinning of dislocations by the Cottrell mechanism.

* This research was supported by the U. S. Atomic Energy Commission.
† John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.

K13. Calculated Frequency Distributions for the Central Force b.c.c. Lattice Model.* CLIFTON BOB CLARK, *Southern Methodist University.*—Some preliminary results will be reported from a study of the familiar Born-von Kármán model for elements having body-centered cubic (b.c.c.) lattice structure, with central interactions among nearest and next-nearest neighbors. The secular equation[1] associated with the model has been solved by the Univac 1103 approximately 40 000 times for each of 12 values of the ratio β of the two central force constants. The output is in the form of a tabular histogram of frequency distribution for each β, where the chosen β-values range from 0.05 to 1. A comparison will be made with the distribution calculated by Fine[2] for tungsten. Another will be made for vanadium between calculated results based on elastic constant measurements by Alers,[3] and the distribution obtained from neutron scattering experiments by Eisenhauer *et al.*[4]

* Work supported by a grant from the National Science Foundation.
[1] J. de Launay, *Solid State Physics*, edited by F. Seitz and D. Turnbull (Academic Press, Inc., New York, 1956), Vol. 2, p. 272.
[2] P. C. Fine, Phys. Rev. **56**, 355 (1939).
[3] G. A. Alers (private communication).
[4] Eisenhauer, Pelah, Hughes, and Palevsky, Phys. Rev. **109**, 1046 (1958).

K14. Statistical Mechanics of the Ideal Inert Gas Solids. G. K. HORTON, *University of Alberta*, AND J. W. LEECH, *Queen Mary College, London, England* (introduced by A. B. Bhatia).—Thermal and mechanical properties of Ne, A, Kr, and Xe are investigated using phenomenological central potentials, based on the crystal data. We make the quasi-harmonic approximation though the zero-point energy is properly taken into account. The forces due to all neighbors are included, though we shall discuss the approximation, that first and second neighbor forces only need be taken into account. Numerical results will be presented on the dispersion law, the compressibility, the thermal expansion coefficient, the specific heat at constant volume and pressure, and Gruneisen's parameter, all as functions of the temperature. We shall discuss the sensitivity of our results with respect to changes in the potentials.

THURSDAY MORNING AT 9:30

New Yorker Terrace Room

(F. N. FRENKIEL presiding)

Fluid Dynamics

KA1. Direct Method of Measuring Density behind Shock Waves. MYRON R. LEWIS AND DAVID B. SLEATOR, *Ballistic Research Laboratories.*—A direct method of measuring velocity and density behind a shock wave in a shock tube is described which uses the *N*-like slip region resulting from the interaction of the shock and a small disturbance The velocity of the slip region along the axis of the shock tube is shown to be the flow velocity. A description of the interaction of a shock wave and a small disturbance is given. Still and streak schlieren photographs and an interferogram of the phenomenon are presented along with a plot of experimental results *versus* theory showing an error of about 1%.

KA2. On the Uniqueness of Solutions for Passage of Shock Waves through Ducts of Variable Cross Section.* GEORGE RUDINGER, *Cornell Aeronautical Laboratory, Inc.*—If shock waves strong enough to produce supersonic flow pass through a convergent duct, and if the shape of the latter is approximated by a single discontinuous area change, there exists a range of the contraction ratio within which three solutions satisfy all required boundary conditions.[1] According to this reference, the appropriate solution is determined by certain entropy considerations, but the given reasoning is unconvincing. Examination of the transient processes that precede the establishment of the final flow suggests, and a general proof confirms, that only one of these solutions can actually occur if the duct converges monotonically. For more general duct configurations, the other solutions may also occur, but the correct wave pattern can be established only with the aid of a wave diagram in which area changes are properly taken into account. For configurations with a throat, additional wave patterns may appear both within and outside of the region of ambiguity which then loses its significance.

* Supported by the Office of Naval Research through Project Squid.
[1] Oppenheim, Urtiew, and Stern, Phys. Fluids **2**, 427 (1959).

KA3. Molecular Radiation from the Relaxation Zone of Shock Waves.* B. KIVEL, J. D. TEARE, AND P. HAMMERLING, *Avco-Everett Research Laboratory.*—The relation between emitted radiation and local translational temperature is considered. At first the radiation depends on an integral from the start of the shock involving the absolute excitation rates. Later, if all of the rates are fast compared to dissociation, a local equilibrium may be established in all aspects except dissociation. Then the density of excited molecular electronic states is uniquely determined by the local properties and is independent of the history of the shock. However, the density for each state depends on the ratio of rates coupling it to the dissociated atoms and to the ground state of the corresponding molecule. The radiating state density is not expected to overshoot its equilibrium value if both the coupling with atoms is strong and the radiating state has about the same energy

as the atoms, since the atom density increases monotonically. An overshoot occurs for a highly excited state coupled to atoms and for a radiating state coupled to the ground molecular state because of the overshoot of temperature and of molecular density. The radiation front, in which binary collision processes dominate, has a linear dependence on the initial pressure at constant shock speed.

* Supported jointly by U. S. Army and Air Force.

KA4. Experimental Off-Hugoniot States for Sodium Chloride and Aluminum.* B. LEROY HORD, *Lawrence Radiation Laboratory, Livermore.*—Experimental pressure-volume points lying off the normal shock Hugoniot have been obtained for sodium chloride and aluminum at shock pressures from 100 to 500 kilobars. Three different techniques were employed with varying success. (1) Initial energy was increased by heating the sample prior to shocking. (2) Samples were subjected to double shocks. The second shock occurs when the initial shock is reflected from a high-density anvil placed on top of the sample. Second-shock parameters in the sample were obtained by measuring the anvil-shock parameters and assuming continuity of pressure and particle velocity across the interface and negligible attenuation in the anvil. (3) Initial densities were reduced by increasing porosity of samples. Shocked porous samples arrive at a state of higher energy for a given pressure resulting from the increased $P\Delta V$ work, hence off-Hugoniot points are attainable. Aluminum information was obtained for a better check on the three techniques as its normal Hugoniot is better established than that of sodium chloride. Of special interest has been the check on the volume dependence of the Grüneisen γ arising from the Mie-Grüneisen equation of state for solids.

* Work was performed under auspices of the U. S. Atomic Energy Commission.

KA5. Hypersonic Nozzle Expansion with Air Atom Recombination Present.* H. T. NAGAMATSU, J. B. WORKMAN, AND R. E. SHEER, JR., *General Electric Research Laboratory.*—An experimental investigation has been conducted on the expansion of high-temperature, high-pressure air to hypersonic flow Mach numbers in a conical nozzle of a hypersonic shock tunnel. The equilibrium temperatures and pressure ranges after the reflected shock wave were 1400° to 6000°K and 100 to 1000 psia. Static pressure measurements, which are sensitive to the state of the gas, were made along the axis of the nozzle for different reservoir conditions. These results are compared with the calculated equilibrium and "frozen" data for the same geometry and initial reservoir conditions. For reservoir pressures greater than 500 psia, the expansion of the air in the nozzle is essentially in equilibrium up to reflected stagnation temperatures of about 4500°K. For stagnation temperatures greater than 4000°K and reservoir pressures lower than 100 psia, the expanding air is almost frozen. At a given area ratio for the nozzle and reflected stagnation pressure, the expansion process remains in equilibrium up to a certain reflected stagnation temperature and beyond this temperature the flow expansion deviates from the equilibrium process rapidly and approaches the frozen case.

* Research supported in part by the Ballistic Missile Division of the Air Force.

KA6. Electromagnetic Structure in a Shock Front. R. W. HALES AND V. JOSEPHSON, *Space Technology Laboratories, Inc.*—Shock waves produced by an electrical discharge in deuterium have been studied. Capacitors charged to 20 kilovolts are discharged between electrodes at the ends of a conical tube.[1] Dimensions of the tube are height, 6 in., end diameters $\frac{3}{4}$ in. and 3 in. The shock fronts are observed in a $\frac{3}{4}$-in. diam tube extending along the axis from the base of the cone. Initial gas pressures are of the order of 100 microns. The frequency of the discharge circuit is 200 kilocycles per second. Initial shock velocities of 10 cm per microsecond are typical, with these velocities attenuating by an order of magnitude along the tube. These velocities have been recorded by a rotating mirror camera, photomultiplier tubes, and electrostatic probes. A positive signal is associated with the shock front. The electrostatic probes also observe a negative pulse which propagates along the tube an order of magnitude faster than the shock front. The effect of interaction of the fronts with a magnetic field, an electrically neutral screen or a screen with either positive or negative potential will be discussed.

[1] V. Josephson, J. Appl. Phys. **29**, 30 (1958).

KA7. Measurement of the Structure of Shock Waves in Helium Plasmas.* WOLFGANG WIESE, H. F. BERG, AND H. R. GRIEM, *University of Maryland.*—Strong shocks were produced in a magnetic shock tube and a small volume element was singled out by a high-resolution optical system. The radiation emitted by this volume element in the He I 5876 and the He II 4686 lines was recorded using a medium dispersion spectrograph with a fast photoelectric system. The over-all time resolution is determined by the optical resolution and is certainly better than 0.05 μsec for the observed shock velocities of about 2 cm/μsec, which are easily obtained at initial pressures in the mm range. The rise times of the photomultiplier signals are always larger, but close to 0.2 μsec for both the neutral helium line and the ionized helium line. Therefore, the time needed to populate the excited states responsible for the radiation to 90% of the equilibrium value is typically 0.2 μsec and the width of the shock front accordingly 0.4 cm. Since most of the excitation is due to electron impacts, this implies that the tail of the electron velocity distribution function is established over a distance of the order of one mean free path for a given electron-velocity.

* Jointly sponsored by GRDC and Office of Naval Research.

KA8. Spectroscopic Study of Helium Plasmas Produced in a Magnetically Driven Shock Tube.* E. A. MCLEAN AND C. E. FANEUFF, *U. S. Naval Research Laboratory,* AND H. R. GRIEM, *University of Maryland and U. S. Naval Research Laboratory.*—The temperature, density, and degree of ionization of plasmas produced by Mach ~30 magnetically driven shock waves in helium (ambient pressure 1 mm Hg) have been measured spectroscopically. Photoelectric intensity measurements (10^{-8} sec time resolution) of the absolute spectral intensities of the He I λ3889, He I λ5876, He II λ3203, and He II λ4686 indicate electron densities of $\sim 10^{17}$ cm^{-3}, a density ratio of ~4 across the shock front, and temperatures of ~3.7 ev. From four combinations of He II and He I lines, the calculated temperatures are self-consistent to $\pm 1.5\%$ and the densities to $\pm 15\%$. The electron density was derived independently from the width of He II λ4686 and agreed with the photoelectric density measurement to within the experimental error for the line width. The temperature calculated from the measured shock velocity is lower by about a factor of two and the density ratio is higher by about the same factor. Magnetic fields have been observed at the shock front but are too small ($H < 400$ gauss) to account for the discrepancy between the spectroscopic and Rankine-Hugoniot temperatures and densities.

* Jointly supported by the U. S. Atomic Energy Commission and the Office of Naval Research.

KA9. Effects of Magnetic Fields and Precursor Radiation the Shock Heating of Plasmas. H. R. GRIEM, *University of Maryland and U. S. Naval Research Laboratory,* AND A. C. KOLB, *U. S. Naval Research Laboratory.*—Measurements of the density and temperature ratios across Mach-30 shocks produced in magnetic shock tubes of the *T*-type are in dis-

agreement by about a factor of two with those predicted by the usual shock theory and indicate that there is an energy density in front of the observed shock which is not negligible compared with that in the shock-heated plasma. Two sources of this energy density were investigated: the magnetic field produced by the current driving the plasma, and the excitation by ultraviolet radiation diffusing into the cold gas with a velocity higher than the shock velocity. Both effects turn out to be of comparable magnitude close to the electrodes but further up the tube the magnetic effect has a negligible influence on the plasma state. The proposed model gives a semiquantitative explanation of the experimental data.

KA10. Limitations of the Hydraulic Analogy due to Finite Amplitude Waves. E. V. LAITONE, *University of California, Berkeley.*—It is first shown that even if only infinitesimal amplitude surface water waves are considered the hydraulic analogy to a two-dimensional isentropic gas flow is always limited to the simple case of surface water waves over a flat horizontal bottom, corresponding to a fictitious gas having a specific heat ratio of two. For example, a triangular cross-section channel should not be used in the analogy. Then it is shown how the second approximation to shallow water theory completely invalidates the hydraulic analogy by always allowing the formation of finite amplitude waves that are propagated without a change in shape or form, completely unlike the gas dynamics behavior that requires that all finite amplitude waves must form a discontinuity or shock wave. These finite amplitude waves are the solitary wave of Boussinesq and Rayleigh, and the conoidal waves of Korteweg and de Vries. Higher order approximations of the shallow water theory are then obtained to show that the vertical accelerations and the vertical velocity cannot be neglected in these higher order terms, and that the solitary wave will form a discontinuity only if its amplitude exceeds 8/11 of the undisturbed original water depth over the flat horizontal bottom.

KA11. Some Studies in Separated Flow Aerodynamics.* S. A. SCHAAF AND L. L. LYNES, *University of California, Berkeley.*—Aerodynamic flows in which separation occurs on a considerable portion of the forward part of the configuration offer a number of promising features. However, very little is known as to the structure of such flows. Accordingly, some experiments were carried out in the Berkeley low-density supersonic wind tunnel to determine pressure distributions for such configurations. The tests were run at $M=6$ and at $Re=10^4$ based on free stream conditions and the model diameter. The geometry investigated was a sphere-nosed cylinder with a 45° conical skirt located a variable distance downstream from the leading edge. Models were tested at 0 and 20° angle of attack. Results were in general agreement with a relatively simple theoretical model for the flow.

* This work was supported jointly by the Office of Naval Research and the U. S. Air Force Office of Scientific Research.

KA12. Mass Transfer into the Hypersonic Laminar Boundary Layer over Blunt Nosed Bodies.* SINCLAIRE M. SCALA AND WILLIAM F. ASHLEY, *General Electric Company, MSVD.*—The multicomponent laminar boundary layer equations which are a coupled set of nonlinear differential equations were derived. Local similarity solutions were obtained on an IBM 704 digital computer for the hypersonic laminar flow of dissociated air over a surface including the effects of air injection. Dissociated air was treated as a four component gas, including atomic oxygen and nitrogen, and molecular oxygen and nitrogen. The thermodynamic and transport properties of the gaseous mixture were calculated in terms of the local gas temperature and gas composition, using the Lennard-Jones model for molecules and the rigid-sphere model for the atomic species. The reduction in hypersonic heat transfer due to mass transfer was determined. In addition, the local variation of the skin friction and the nominal displacement and momentum thickness of the boundary layer are presented as a function of the mass efflux at the wall. Each of the physical variables of interest was determined for the full range of hypersonic flight conditions.

* This work was supported in part by the U. S. Air Force, Ballistic Missiles Division.

Business Session of the Division of Fluid Dynamics

(to be convoked during this session whenever the Chairman chooses)

THURSDAY AFTERNOON AT 2:00

Manhattan Center

(V. F. WEISSKOPF presiding)

Joint Ceremonial Session of APS and AAPT

Retiring Presidential Address of The American Physical Society

L1. Some Recent Progress in Statistical Mechanics. G. E. UHLENBECK, *University of Michigan.*

(F. W. SEARS presiding)

L2. Presentation of the Oersted Medal of the AAPT. C. J. OVERBECK, *Northwestern University* (Chairman of AAPT Committee on Awards).

Nineteenth Richtmyer Memorial Lecture

L3. Physics in Space. J. A. VAN ALLEN, *State University of Iowa.*

FRIDAY MORNING AT 9:15

New Yorker Grand Ballroom

(W. M. ELSASSER presiding)

Invited Papers of the Divisions of Fluid Dynamics and Plasma Physics

M1. Ionic Heating and Confinement of a Magnetized Plasma. HANNES ALFVEN, *Royal Institute of Technology, Stockholm.* (25 min.)

M2. Idealized Problems of Plasma Dynamics Relation to Magnetic Storms. SYDNEY CHAPMAN, *University of Alaska.* (25 min.)

M3. Thermonuclear Plasma Containment in Open-Ended Systems. HAROLD GRAD, *New York University.* (25 min.)

M4. Theory and Experiment in Plasma Stability. MARSHALL ROSENBLUTH, *General Atomic.* (25 min.)

FRIDAY MORNING AT 9:30

Statler-Hilton Penn Top South

(W. W. BUECHNER presiding)

Nuclear Reactions and Nuclear Energy Levels I

MA1. T(p,n)He^3 Reaction, II.* J. E. YOUNG, *Los Alamos Scientific Laboratory.*—Our previously reported analysis of this reaction has been refined. First, it is possible to establish formally the reaction model in a rigorous way. This is done from the multiple scattering theory of inelastic processes involving direct interactions. The model is that of competing knock-on and proton capture by a diparticle. Next, the interactions noted are characterized by two-body t matrices of the Yamaguchi type. In the knock-on process nucleons scatter only in even states, characteristic of the Serber mixture employed. The proton-diparticle t matrix is that for doublet states only. Consequently, its parameters are determined from the n-d doublet scattering length and binding energy of He^3. No free, or undetermined, parameters appear in the theory. Programmatic evaluation of the cross section is in progress. Numerical results will be reported for 1.75- to 5-Mev protons.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

MA2. Three-Body Breakup as a Sequence of Two-Body Processes. G. C. PHILLIPS AND L. C. BIEDENHARN, *The Rice Institute.*—In lieu of a comprehensive treatment of nuclear reactions that involve energetically allowed three-body breakups, the suggestion is discussed that a sequence of two-body processes furnishes a very useful approximation.[1] Such a procedure is particularly indicated by the "cluster model" for describing the gross features of low-energy nuclear states.[2] The description of the breakup of the excited nuclear clusters emitted in the first of a sequence of two-body decays is conveniently described by a "generalized density of states," ϱ_P. For a pure state of the excited cluster produced by the first transition, one finds the approximate result $\varrho_P \propto (\sin\tilde{\delta})^2/P$, where $\tilde{\delta}$ is (the nuclear part of) the phase shift of the cluster states (measurable, at least approximately, from two-body reactions involving this state) and P is the penetration factor appropriate to the particular decomposition. We shall illustrate the application of this approximation by discussing several nuclear reactions. Reactions involving the unstable nucleus Be^8 are particularly good illustrations of the method, and our discussion will include the beta decays of Li^{8*} and B^{8*}, and the reaction Be^9(p,d)Be^8.

[1] This suggestion is, of course, not new. See, for example, A. M. Lane and R. G. Thomas, Revs. Modern Phys. 30, 257 (1958).
[2] G. C. Phillips, Bull. Am. Phys. Soc. Ser. II, 4, 99 (1959); a more general form of the cluster model has been given by T. Kanellopoulos and K. Wildermuth, Nuclear Phys. 7, 150 (1958).

MA3. Be^9(γ,n) Cross Section at 1.69 and 1.78 Mev. W. JOHN, F. J. LOMBARD, E. T. MOORE, AND J. M. PROSSER, *Lawrence Radiation Laboratory, Livermore.*—A spherical Sb^{124} source was placed in the center of a spherical shell of beryllium. The total neutron yield was measured by submerging the source in a manganous sulfate bath which was calibrated by a National Bureau of Standards Ra-Be source. The gamma-ray strength was determined from the area under the NaI photopeak. The photopeak method has the advantage of being independent of the decay scheme. Our result, $\sigma = (13.3 \pm 1.1) \cdot 10^{-28}$ cm^2 agrees with the value recently published by Gibbons *et al.*[1] Thus the long-standing discrepancy between previous measurements is apparently resolved. The ratio of the cross section at 1.78 Mev to that at 1.69 Mev was found to be 0.62 ± 0.02 by comparing an Al^{28}–Be source to the Sb–Be source, using a long counter for the neutrons. The cross section at 1.78 Mev is then $(8.2 \pm 0.7) \cdot 10^{-28}$ cm^2.

[1] Gibbons, Macklin, Marion, and Schmitt, Phys. Rev. 114, 1319 (1959).

MA4. Gamma Radiation from Be^9(n,γ)Be^{10}. W. D. BARFIELD,* H. T. MOTZ, AND R. E. CARTER, *Los Alamos Scientific Laboratory.*†—The Omega West Reactor Compton spectrometer[1] has resolved γ rays of 3365 and 3441 kev from Be^9(n, γ)Be^{10}, and they are found not to have equal intensities as has been previously assumed.[2] The transition of 3365 kev from the first excited state to ground is 2.7 times as intense as the 3441-kev transition indicating feeding of another decay mode from the 6806-kev thermal neutron capturing state. Gamma rays of 855 ± 3 kev and 2589 kev which account for this feeding have been found in addition to the previously unassigned 5950-kev line[2] and the ground-state γ ray of 6803 kev. The 855-kev transition occurs from the capturing state to a known level of 5960 kev and is much stronger relative to

the 6803-kev ground-state dipole transition than would be expected. We have measured the energies of the quoted γ rays to an accuracy of about 1 part in 10^3 except for the 855-kev γ ray.

* Temporary address: Rice Institute, Houston, Texas.
† Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Motz, Carter, and Fisher, Bull. Am. Phys. Soc. Ser. II, **4**, 246 (1959).
[2] G. A. Bartholomew and B. B. Kinsey, Can. J. Phys. **31**, 49 (1953).

MA5. Photodisintegration of Be^9 and C^{13}. D. T. Goldman and N. C. Francis, *Knolls Atomic Power Laboratory*,* and E. Guth, *Oak Ridge National Laboratory*.—The usefulness of the application of the direct interaction model in the analyses of Be^9 and C^{13} (γ, n) cross sections has been investigated. In the first set of calculations a square well was assumed for the distorting potential. The energy dependence of the cross section then depends on the square of the continuum wave function evaluated at the nuclear radius. The theory of effective range was used to evaluate the wave function at the nuclear radius. For the C^{13} reaction, the scattering length and effective range were extracted from the analysis of C^{12} neutron elastic-scattering data. The absolute $C^{13}(\gamma,n)$ cross section was found by using detailed balance and the $C^{12}(n,\gamma)$ thermal result. The difference between the experiment and predicted single-particle results will be discussed. The Be^8+n scattering length that was used is consistent with the charged-particle Be^9 reaction cross-section results. The effective range was fixed by requiring that the calculated (γ,n) cross section exhibit its known energy variation at low energies. The existence of a second single-particle resonance at 3 Mev was also investigated. T..e differential cross section and its energy dependence near 3 Mev was calculated on the assumption that it is either a $d_{\frac{1}{2}}$ or a $p_{\frac{1}{2}}$ resonance.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

MA6. The Levels in B^{10} at 7.56 and 5.16 Mev. N. W. Tanner, R. E. Meads, J. E. G. McIldowie, and S. S. Hanna.*—A study has been made of the prominent transition[1] between the 7.56- and 5.16-Mev levels of B^{10}. Observations obtained with a three-crystal spectrometer confirm[1] the value of 2.40 Mev for the energy of the radiation, eliminating the possibility that the transition is to the 5.11-Mev state. The intensity of the gamma ray clearly indicates dipole radiation. Hence, either the 0^+ assignment to the 7.56-Mev level or the 2^+ assignment to the 5.16-Mev level is in error. To investigate the former possibility, the γ-γ directional correlation in the 7.56-Mev $\rightarrow$ 0.72-Mev $\rightarrow$ 0 cascade was measured with the result, $W(\theta)=1-(0.08\pm0.01)\cos^2\theta$, which supports the previously well-established assignment of 0^+ to the upper level. Alternatives to the assignment of 2^+, $T=1$ for the 5.16-Mev level will be discussed.

* Permanent address: Argonne National Laboratory.
[1] W. E. Meyerhof and N. W. Tanner, Phys. Rev. (to be published).

MA7. (d,n) Stripping Studies on B^{10} and B^{11}. A. J. Ferguson, H. E. Gove, A. E. Litherland, and R. Batchelor,* *Chalk River Laboratories*.—The stripping reactions $B^{10}(d,n)C^{11}$ $B^{11}(d,n)C^{12}$ to excited states of the final nuclei have been studied using a coincidence-counter technique. Neutrons are observed in a liquid scintillator movable in a plane containing the incident deuteron beam, in coincidence with gamma rays of specific energy measured in a NaI(Tl) detector fixed perpendicular to the plane. In Born approximation such correlations are identical with the corresponding direct-neutron distribution in the absence of interfering proton orbital angular momenta. Similar considerations apply to other direct interactions. Angular correlations have been measured in this way for the 6.50-Mev state of C^{11} and the 15.11-Mev state of C^{12} at deuteron energies of 5 and 8 Mev, respectively, using the Chalk River tandem accelerator. Both distributions show $l_p=1$ stripping patterns. (n,γ) correlations in another geometry for the C^{12} 15.11-Mev state give an intensity ratio of 12:1 between channel spins 2 and 1, which is not compatible with either a pure j-j or L-S coupling scheme. Absolute yield measurements indicated that the reduced proton width for the 15.11-Mev level in C^{12} is of the order of magnitude of the single-particle width.

* Seconded from A.W.R.E., Aldermaston.

MA8. Stripping near Threshold: Anisotropy of the 170-kev Gamma Ray from the $C^{12}(d,p\gamma)C^{13*}$ Reaction.* L. F. Chase, Jr., E. K. Warburton,† and R. G. Johnson, *Lockheed Missiles and Space Research Laboratory*.—This work was undertaken to further substantiate the predictions of Wilkinson[1] that deuteron-induced reactions with low Q values and for low-deutron bombarding energies would show good stripping character. The method employed in the present work considers the de-excitation gamma ray following a $X(d,f)Y^*$ reaction (i.e., the gamma ray associated with the de-excitation of Y^*). For $l_f>0$ the gamma ray will not, in general, be isotropic, and its angular distribution can be derived for the alternate cases of stripping and compound nucleus formation. The reaction studied was the $C^{12}(d,p\gamma)C^{13*}$ and the gamma ray observed was the 170-kev gamma ray from the transition between the 3.85-Mev and 3.68-Mev states in C^{13}. The excitation function ($Q=-1.13$ Mev) and the anisotropy (obtained from the gamma-ray yield at 0° and 90° with respect to the incident-deuteron beam direction) of the 170-kev gamma ray has been measured with a thin C^{12} target (approximately 7 kev) for deuteron energies from 1.6- to 3.2-Mev. The anisotropy as a function of deuteron energy, as well as the excitation function, will be presented and discussed in terms of the reaction mechanisms.

* Supported by the joint program of the U. S. Atomic Energy Commission and the Lockheed General Research Program.
† Permanent address: Princeton University.
[1] D. H. Wilkinson, Phil. Mag. **3**, 1185 (1958).

MA9. Inelastic Neutron-Gamma Angular Correlation for the $C^{12}(n,n'\gamma)C^{12}$ Reaction. R. B. Theus, A. H. Aitken, and L. A. Beach, *U. S. Naval Research Laboratory*.—The azimuthal correlation of inelastically scattered neutrons and γ rays from 14-Mev neutrons on C^{12} has been measured. The resultant azimuthal distribution was found to be isotropic for the inelastic neutrons and γ rays scattered at right angles to the incident neutron beam. The plane wave treatment of the direct interaction theory of Levinson and Banerjee[1] predicts an anisotropy of 6.2 and 13.4 for the case of j-j and L-S coupling, respectively, for the two odd nucleons. These predictions are greater than 50 standard deviations from the data. Further comparisons between theory and experiment will be presented.

[1] C. D. Levinson and M. K. Banerjee, Ann. Phys. (N.Y.) **2**, 499 (1957).

MA10. $C^{12}(He^3,p)N^{14}$ and $C^{12}(He^3,d)N^{13}$ Angular Distributions at 13.9 Mev.* J. R. Priest, D. J. Tendam, and E. Bleuler, *Purdue University*.—By using the 14-Mev He^3 beam from the Purdue University cyclotron, the angular distributions of the protons which leave the N^{14} nucleus in the ground state, first excited state, and second excited state have been measured from $\sim$12° to $\sim$170° (c.m.) and the angular distribution of the deuterons which leave the N^{13} nucleus in its ground state has been measured from $\sim$12° to $\sim$150° (c.m.). The angular distributions exhibit diffraction-type patterns and are strongly peaked in the forward direction. The (He^3,d) cross section being about 35 mb/sterad at 12° and dropping to about 2.0 mb/sterad at 85° where a secondary maximum occurs, is a factor of ten larger than the (He^3,p)

cross sections measured. The $C^{12}(He^3,d)N^{13}$ angular distribution is similar to those at higher bombarding energies.[1]

* Supported in part by the U. S. Atomic Energy Commission.
[1] H. E. Wegner, Los Alamos Scientific Laboratory (private communication).

MA11. Inelastic Scattering of Protons by Carbon from 5.3 to 6.0 Mev.* HAJIME YOSHIKI AND NIKOLA NIKOLIC, *Columbia University.*—The inelastic scattering of protons from carbon in the range of bombarding energies 5.3 to 6.0 Mev has been investigated. A thin polystyrene film was used as a target. A thin CsI crystal was directed at the proton angle of 111° to avoid recoil nuclei and protons from p-p scattering. The excitation curve shows, beside the resonance corresponding to the previously reported 6.91-Mev ($\frac{3}{2}^+$) and 7.42-Mev ($\frac{5}{2}^+$) levels in N^{13},[1] a weak resonance at 5.69 Mev with a measured laboratory width of about 20 kev. The results of (p',γ) angular correlation measurements at several different proton energies show a certain anomaly from the compound nucleus theory at the higher energies.

* This work partially supported by the U. S. Atomic Energy Commission.
[1] Lidofsky, Weil, Bent, and Jones, Bull. Am. Phys. Soc. Ser. II, 2, 29 (1957).

FRIDAY MORNING at 10:30

New Yorker Terrace Room

(J. A. VAN ALLEN presiding)

Space Physics

N1. Giant Solar Flare Neutrons. SERGE M. LAPOINTE, *Université de Montréal.*—An attempt is made to put a limitation on the origin and acceleration mechanisms of solar flare protons. The method utilized investigates how a beam of protons traversing the solar atmosphere could generate neutrons by nuclear reactions. One then looks for a sign of these neutrons on earth. From the observations, it is inferred how much of the solar atmosphere the proton beam has traversed. An integral intensity of 3×10^{32} protons at 3 Bev is adopted. Two integral spectra are examined proportional to $(pc)^{-7}$ and $(pc)^{-8}$. The reaction with hydrogen is $p+p->p+n+\pi^+$. Neutron flux and spectrum on earth are calculated. The neutron monitor at Wellington on February 23, 1956, is selected. The over-all detection efficiency is ascertained taking into account neutron decay in flight (1/1.4), oblique incidence (1/50), and the relative response to primary neutrons. An upper limit to the neutron flux is arrived at leading to a maximum of 1 or 2 g/cm² of solar atmosphere intervening. Mechanisms accelerating protons in regions situated above the body of the visible flare are seen to be in better agreement with the present calculations.

N2. Fluctuations in Intensity of High Altitude Radiation in the Trapped Radiation Zone. ALAN ROSEN, *Space Technology Laboratories.*—An analysis of the data obtained from the scintillation counter on the Explorer VI earth satellite during the period of August 7, to September 10, 1959, reveals two distinct types of fluctuations. The first involves day to day changes in intensity along lines of constant geomagnetic latitudes. The significance of these changes will be discussed in terms of solar radio noise, geomagnetic storms, sunspot activity, and aurora observations. The second type of fluctuation, observed at radial distances of 35 000 to 48 000 km from the earth center, occurs in a time interval of less than a second to a second to a few minutes. These are sharply rising peaks, which sometimes reach an intensity up to 100 times the normal value. The daily variation of the magnitude, and the distance at which these fluctuations occur, will be presented. The scale size and theoretical mechanisms which may account for them will be discussed.

N3. Soft Radiation Measurements on the Explorer VI Earth Satellite. THOMAS A. FARLEY, *Space Technology Laboratories.*—The spatial distribution of trapped radiation in the Van Allen zones as measured by a scintillation counter sensitive to electrons above 200 kev and protons above 2 Mev is presented by means of isointensity plots, curves showing variations with radial distance at constant geomagnetic latitude, and curves showing variations with geomagnetic latitude at constant radial distance. A charged particle flux in excess of 10^3 particles/cm² sec has been observed in regions of high intensity near the geomagnetic equator. At high southern latitudes outside the zones of trapped radiation, a low counting rate has been observed. The rate is approximately constant over a wide range of latitudes and radial distances, but shows occasional daily variations.

N4. Energy Spectra and Spatial Distributions of Electrons Trapped in the Earth's Magnetic Field. J. B. CLADIS, J. F. CHASE, JR., AND W. L. IMHOF, *Lockheed Missiles and Space Research Laboratory,* AND D. J. KNECKT, *Air Force Special Weapons Center.*—A four-stage, solid propellant rocket was used to obtain measurements of the trapped radiation. The rocket was launched from Wallops Island, Virginia, and reached an altitude of 1045 km. Along the ascent trajectory, the rocket generally followed magnetic lines of force, permitting measurements to be made along the reflection points of the radiation trapped in the outer zone. Along the descent trajectory, data were taken as the rocket crossed magnetic lines of force which define the saddle point between the inner- and outer-radiation zones. Directional intensities and energy spectra were obtained of electrons in the energy interval from 30 kev to about 1 Mev with a collimated magnetic deflection spectrometer. The total directional flux was also measured which included electrons of energy greater than about 1.5 Mev and protons of energy greater than about 1 Mev. A Schonstedt magnetometer was used to correlate the direction of the measurements with the direction and intensity of the geomagnetic field. The results will be given as a function of the position of the rocket in flight.

N5. Density Distribution in an Ionized Exosphere.* S. F. SINGER, *University of Maryland.*—The exosphere is the region above the ionosphere where the density is low enough so that collisions may be neglected. Hence, the electron density cannot be obtained by an approach which implicitly assumes a condition of thermodynamic equilibrium; for example, the application by many authors of Saha's formula in one form or another is not justified. While for the neutral portion of the exosphere[1] only the gravitational field is active ans spherical symmetry may be assumed, in the present case the motion of ions is controlled by both gravitational and magnetic fields; as a consequence, cylindrical symmetry occurs about the dipole axis. Solutions have been obtained with a good degree of approximation and have been used, together with the extended Liouville theorem, to calculate the relative electron dnesity along various magnetic lines of force. The results of this *a priori* theory are in close agreement with electron densities obtained

from an analysis of the dispersion of radio whistlers out to 2 earth radii.

* Supported in part by the Air Force Cambridge Research Center.
[1] E. J. Öpik and S. F. Singer, Phys. Fluids **2**, 653 (1959).

N6. Wake of Charged Body Moving in a Plasma.* E. H. WALKER AND S. F. SINGER, *University of Maryland.*—When a charged body moves through a plasma pervaded by a magnetic field, Coulomb scattering near 90° puts ions into "quasi-trapped" orbits. With the magnetic field nearly parallel to the body's velocity vector, these ions remain in the vicinity of the body for some time before being scattered out again. As a result, a charge cloud may build up around the body. By setting up and solving the appropriate diffusion equations we can calculate the density distribution of the charge cloud. We discuss the dependence of the equilibrium distribution on the charge and size of the body, the strength of the magnetic field, and the density and temperature of the plasma. We also investigated the time constants associated with buildup and decay; they are important in the discussion of motion through nonuniform plasmas or nonuniform magnetic fields. We apply our theory to the problem of earth satellites moving through the outer ionsphere and discuss the formation of satellite "ghosts."

* Supported in part by a research grant of the Douglas Aircraft Company.

N7. Energy Spectrum of Geomagnetically Trapped Protons.* A. M. LENCHEK AND S. F. SINGER, *University of Maryland.*—The experimentally determined energy spectrum of hard protons[1] in the inner radiation belt is in apparent disagreement with the spectrum predicted from the neutron albedo theory.[2] (The agreement claimed by Hess[3] we believe to be in error.) The real cause of disagreement appears to be the variation with altitude of the maximum energy which can be trapped by the geomagentic field.[4] The photographic emulsion in the experiment of Freden and White does not really measure the energy spectrum at 1200 km, but integrates contributions over a considerable altitude interval since the magnetic lines of force encountered by their rocket actually span an altitude range from 2500 to 4500 km in the plane of the magnetic equator. The analysis also leads to conclusions about the latitude and angular dependence of the trapped proton intensity.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] S. C. Freden and R. S. White, Phys. Rev. Letters **3**, 9 (1959).
[2] S. F. Singer, Phys. Rev. Letters **1**, 171; **1**, 181 (1958).
[3] W. N. Hess, Phys. Rev. Letters **3**, 11 (1959).
[4] S. F. Singer, Phys. Rev. Letters **3**, 188 (1959).

N8. Magnetic Effects of Outer Radiation Belt.* J. R. APEL, S. F. SINGER, AND R. C. WENTWORTH, *University of Maryland.*—Geomagnetically trapped particles are believed to produce a ring current which accounts for many of the magnetic storm effects observed at sea level.[1] We have used the same theory to calculate the magnetic effects at higher altitudes produced by the electrons of the outer radiation belt, i. e., the magnetic field which would be observed by a space probe traveling outward from the earth's surface. In the linear approximation, the magnetic fields arising from the drift and from the gyration of the trapped particles are superimposed on the earth's dipole field. In a self-consistent field calculation, this treatment is modified. For the present calculation, we have used the electron flux values and energy spectra obtained by Vernov *et al.* in Lunik I. The final results are compared with the magnetometer observations carried out in Lunik I. We can also derive limits to the form of the electron spectrum at low energies.

* Supported in part by the U. S. Air Force Geophysical Research Directorate.
[1] S. F. Singer, Trans. Am. Geophys. Union **38**, 175 (1957).

N9. Lifetimes of Artificially Created Radiation Belts.* R. C. WENTWORTH AND S. F. SINGER, *University of Maryland.*—The lifetime of trapped particles in the geomagnetic field depends on their nature and energy, on the location of the injection point, on the "noisiness" of the field, and other factors. In general, particles are removed from the trapped condition when their magnetic moment is changed, either by charge exchange, by magnetic or atomic scattering, or by various energy losses. Here we consider only the effects of a tenuous atmosphere on the lifetime of relativistic (2–10 Mev) electrons. After injection, a transient decay phase occurs during which the distribution approaches a quasi-steady-state. While the latter case has been discussed using a Fokker-Planck approach,[1] the transient case can be adequately handled by considering diffusion of trapped particles on the surface of the momentum sphere. As a consequence of the transformation in pitch angle as a particle gyrates along a line of force, the lifetime is determined mainly by the atmospheric density in the *equatorial* plane and not by the density at the mirror points. This result is applied to the data of the Argus tests, and also to an experiment in which electrons are injected by an accelerator.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] Wentworth, MacDonald, and Singer, Phys. Fluids **2**, 499 (1959).

N10. A Relationship between the Lower Ionosphere and [OI] 5577 Nightglow Emission. W. S. HOUGH AND J. W. MCCAULLEY, *Boulder Laboratories, U. S. National Bureau of Standards.*—During the International Geophysical Year, data have been accumulated on various phenomena occurring in the lower ionosphere. These data include observations of the 5577 A airglow emission line and ionosphere characteristics observed by low frequency sweep soundings. This paper is a first attempt to correlate these phenomena, and it is hoped that the results will contribute to a better understanding of the physical processes in the lower ionopshere. This analysis suggests that 5577 airglow intensity variations can be correlated with variations of an ionosphere stratum. This stratum, as observed by low-frequency sweep soundings is in the 90–110 km region. It is concluded that the observations do not uniquely support a three-body photochemical reaction as a 5577 excitation mechanism, and do not eliminate the possibility that a mechanism involving electrons may exist. Other correlations will be discussed.

FRIDAY MORNING AT 9:45

Statler-Hilton Ivy Suite

(H. EHRENREICH presiding)

General Solid-State Physics

NA1. X-Ray Photoconductivity of Some Sulfide Phosphors. G. DÉJARDIN AND J. JANIN, *Université de Lyon.*—The phosphors studied include a common electroluminescent product, two sulfides showing different increases of their x-ray excited luminescence under the action of an electric field (electro-enhancement effect), and a sulfide exhibiting the opposite

effect of electroquenching. A layer (0.5 mm) of each powder, deposited between electrodes consisting of a plate and a fine grid, is subjected, in a good vacuum, to an electric field. Measurements have been made of the dark current and of the photocurrent induced by x-ray irradiation. The relationships between the photocurrent and several factors (field strength, amount, and penetrating power of the exciting radiation) have been investigated. The photocurrent varies approximately as powers of the grid voltage (up to 250 v), of the electron current, through the x-ray tube and of the high voltage applied to it, the exponent depending, for each phosphor, on the values of the two factors which remain unchanged. The experimental results show that the behaviors of the four sulfides are not very different; they sustain the opinion according to which the electroenhancement effect cannot be explained by a classical mechanism of electron acceleration (G. Destriau).

NA2. Color Centers in Cesium Halide Single Crystals.* P. AVAKIAN AND A. SMAKULA, *M.I.T.*—CsCl crystals have been grown from solution with urea activator and from the melt using a double run Bridgman method. The infrared absorption spectra of the solution grown crystals showed about 0.01% NH_4 but no water contamination. CsBr and CsI crystals have been grown from the melt only. Coloration was produced by 130 kev x-rays, 3.0 Mev electrons, and by electrolysis. In CsI coloration resulted from electrolysis only. The absorption of uncolored and colored crystals has been measured from 0.175 to 3.5 μ at 20, −80, and −190°C. All three crystals show one strong band in the visible and several weaker bands at shorter and longer wavelengths which shift with temperature change. The spectral positions in mμ for a number of the bands at −80°C are

CsCl	1172	1005	876	741	*590*	430	365
CsBr	1290	1066	915	800	*665*		390
CsI		1198			*770*	532	430

The strongest band behaves similarly to the *F* band in other alkali halides. The *F* bands can be bleached by light, and their spectral positions approximately follow the Mollwo relation (λ_{max} = const d^n where d = lattice constant and $n = 2.5$).

* Supported by the Office of Naval Research.

NA3. Color Centers in CsCl-Type Alkali Halides. HERBERT RABIN, JAMES H. SCHULMAN, AND ROBERT F. MARZKE, *U. S. Naval Research Laboratory.*—Measurements of coloration in CsCl, CsBr, and CsI induced by ionizing radiation have been made at room, liquid nitrogen, and liquid helium temperatures. Melt grown and solution grown crystals prepared at NRL and MIT[1], were studied, as well as cyrstals obtained from commercial sources. It has been found that x-ray coloration can be produced easily in CsCl and CsBr and a variety of color centers appear at room and low temperatures. The principal room temperature absorption band in CsCl and CsBr (at approximately 605 mμ and 680 mμ respectively) is resolved into at least a triplet band structure in CsCl and at least a doublet structure in CsBr at liquid helium temperature. The structure appears to be associated with a single center, most likely the *F* center, and is observed if the centers are initially produced at either room or liquid helium temperature. CsI shows little or no absorption under x-ray irradiation at any temperature, and under 2-Mev electron bombardment does not color at room temperature. Under electron irradiation at liquid nitrogen temperature absorption bands can be produced in CsI, suggesting the defects are produced by atomic displacements.

[1] Kindly provided by Professor A. Smakula and Mr. P. Avakian.

NA4. Anionic Diffusion and Electrical Conductivity in KCl.* H. W. SCHAMP, JR., *University of Maryland.*—The diffusion coefficient of Cl^{36} in KCl and the electrical conductivity of KCl have been measured in the temperature range from about 700°C to below 400°C. The diffusion coefficient, D, calculated from the conductivity measurements by means of the Einstein relation can be represented quite well by the equation $D = 1.7 \times \exp(-21\,900/T)$. The knee of the curve occurs at about 450°C. If the temperature at which the knee occurs is used as a criterion for estimating the purity of the salt, then one concludes that the salt used in these measurements is somewhat higher in purity than that used by Kerkhoff[1] in measurements of the transference numbers. The measured diffusion coefficient of the chlorine ion, D_{Cl}, exhibits an activation energy which is close to that calculated from the ionic conductivity. If the ratio, D_{Cl}/D, is taken as a measure of the transference number, n^-, of the negative ion, then it appears that n^- is of the order of 0.2 over the temperature range investigated. This is not in agreement with the measurements of Kerkoff which indicated that the transference numbers of very pure KCl exhibit a stronger temperature dependence than do those of less pure KCl.

* Supported in part by the U. S. Atomic Energy Commission.
[1] F. Kerkhoff, Z. Physik **130**, 449 (1951).

NA5. Electronic Structure of the Cuprous Halides. FRANK HERMAN AND DONALD S. MCCLURE, *RCA Laboratories.*—With the aid of crystal field theory and energy band theory, we have interpreted the optical absorption spectra of CuCl, CuBr, and CuI. According to our interpretation, the weak absorption peak in the spectra of each of these compounds lying at about 3 ev is due to a $3d^{10}$ to $3d^9$ $4s$ transition within the Cu^+ ion; the strong absorption peak occurring in CuCl at 6.5 ev, in CuBr at 5.6 ev, and in CuI at 4.9 ev is due to the transfer of an electron from the halide to the Cu ion. In the language of energy band theory, the lowest conduction band and the highest valence band arise from the $4s$ and $3d$ states of the Cu^+ ion, respectively, while the next lowest valence band arises from the $3p$ Cl^-, $4p$ Br^-, and $5p$ I^- states. There are two forbidden bands, one between the $4s$ and $3d$ Cu^+ bands, and another between the $3d$ Cu^+ and the p halide bands; the optical energy gap is determined by the width of the former. It is now clear that our previous inability to reconcile the optical gap of CuBr with those of the other members of the isoelectronic sequence Ge-GaAs-ZnSe-CuBr results from the reversal in order of the cation $3d$ and anion $4p$ bands. (In Ge, GaAs, and AnSe, the $3d$ bands of Ge, Ga, and Zn appear to lie *below* the $4p$ bands of Ge, As, and Se.)

NA6. Low-Temperature Thermal Resistivity of Point Defects. PETER CARRUTHERS, *Cornell University.*—The scattering of phonons by a displacement field varying as $1/r^2$, appropriate to vacancies and interstitials, is calculated using the author's formulation of strain field scattering.[1] It is found that for small wave vector q (corresponding to temperatures below the low temperature maximum in the conductivity), the relaxation time varies as q^{-4}, and is much larger than expected from "Rayleigh" scattering. For larger q the specific strain field scattering vanishes. As a striking example of this we discuss the following experimental fact, namely that the depression in the conductivity caused by isotopes (with $\tau^{-1} \propto \omega^4$) is comparable both above and below the peak, while that due to strain field scattering by point defects is large below, but small above the peak. The recent experiments of Pohl[2] on the influence of *F*-centers on the thermal conductivity of LiF are analyzed. The reasons for the disagreement of the present result with that of Klemens,[3] who obtained no scattering, will be explained Some other new results will be mentioned briefly.

[1] P. Carruthers, Phys. Rev. **114**, 995 (1959).
[2] R. Pohl (to be published).
[3] P. G. Klemens, Proc. Phys. Soc. (London) **A68**, 1113 (1955).

NA7. Anomalous Dielectric Loss in Al_2O_3.* N. M. TALLAN† AND D. P. DETWILER,‡ *State University of New York College of Ceramics at Alfred University.*—Measurements have been made in vacuum between −160°C and 400°C, of the dielectric loss of Linde flame-fusion grown single crystal Al_2O_3 at frequencies between 100 cps and 100 000 cps. A characteristic loss peak is found in this region, whose activation energy and position on the temperature scale are dependent upon the previous treatment of the specimen. Exposure to moist air, dry hydrogen, or HCl solution results in a large, broad loss peak near 400°C with an activation energy of approximately 0.5 ev. Heating in vacuum at 400°C results in a gradual sharpening of the loss maximum, together with a progressive shift to lower temperature, diminution of amplitude, and decrease of activation energy to a final value of about 0.3 ev. These changes are reversible. This behavior is attributed to the penetration of hydrogen along dislocation lines and its binding in the strained regions of the lattice surrounding the dislocations.

* This work supported in part by the Office of Scientific Research, ARDC, U. S. Air Force.
† Now at Wright Air Development Center.
‡ Now at Alfred University.

NA8. Lattice Thermal Conductivity and *F*-Centers.* R. O. POHL, *Cornell University.*—An attempt has been made to investigate the influence of point defects on the lattice thermal conductivity by measuring LiF containing photochemically produced *F* centers. The concentration of *F* centers was determined by measuring the optical absorption and using Smakula's formula. Successive irradiations of the same specimen provides good experimental accuracy (background imperfections, geometry). Irradiation causes the thermal conductivity to decrease strongly on the low-temperature side of the maximum, whereas on the high-temperature side the decrease is quite small. The results are in fair agreement with Slack's[1] investigations of the thermal conductivity of calcium-doped KCl, but cannot be explained by Klemens'[2] theory for the phonon scattering by point defects. An attempt is made to explain the results assuming the *F* centers to be randomly distributed and by using a different cutoff mechanism for the long wavelength phonons, as suggested by Callaway.[3]

* Supported by the National Science Foundation and the U. S. Atomic Energy Commission.
[1] G. A. Slack, Phys. Rev. **105**, 832 (1957).
[2] P. G. Klemens, *Solid State Physics*, (Academic Press, Inc., New York, 1958), Vol. 7.
[3] J. Callaway, Phys. Rev. **113**, 1046 (1959).

NA9. *F*-Band in Thallium-Doped Potassium Halides. J. J. MARKHAM AND H. N. HERSH, *Zenith Radio Corporation.*—The half-width and the position of maximum optical absorption associated with the *F* center have been measured in thallium-doped potassium halides—KCl, KBr, and KI. The coloration was made by x-irradiation and the measurements were taken between 5°K and 300°K. The data are given and arguments presented leading to the conclusion that *F* centers are only formed in good regions of the crystal (not near Tl^+).

NA10. On the Origin of Distortions Produced by Ni^{2+} on Tetrahedral Lattice Sites. P. K. BALTZER, *RCA Laboratories* (introduced by P. J. Wojtowicz).—All the 3*d*-electronic states of Ni^{2+} have been calculated, including *L-S* coupling, for the case in which this ion is subjected to the crystalline fields of tetrahedral and octahedral lattice sites which have cubic, tetragonal or trigonal symmetry. The origin of the low-symmetry distortion that Ni^{2+} induces on tetrahedral lattice sites, a point of considerable interest and debate, has been resolved. *A general criterion for predicting the occurrence of induced spontaneous distortions is that the distortion perturbation lowers the energy of at least one component of the electronic ground state.* The Jahn-Teller theorem is applicable only for the special case when the trace of the distortion perturbation over all the components of the electronic ground state is zero, and then only a degenerate ground state will induce distortions. When this trace is nonzero, spontaneous distortions may or may not be induced for either degenerate or non-degenerate ground states. The *L-S* interaction (1000 cm^{-1} for Ni^{2+}) in general makes the trace over any state nonzero for a perturbation acting only on the spatial part of the wavefunctions. It is calculated that the singlet ground state of Ni^{2+} in tetrahedral lattice sites in oxides is lowered in energy 1000 cm^{-1} by a 10% tetragonal distortion.

NA11. Beryllium Oxide "Flagpole" Whiskers. P. L. EDWARDS AND R. J. HAPPEL, JR., *U. S. Naval Ordnance Laboratory.*—Beryllium oxide whiskers with a sphere at the end, called "flagpole" whiskers, have been grown by heating beryllium metal to 1450°C in the presence of hydrogen or helium containing traces of water vapor. Some of the flagpole whiskers have straight sides with diameters of 1 μ and greater, lengths to 1 mm, and are topped with balls of 10–100 μ diam. Other whiskers are tapered toward the base. As seen in the microscope, the spheres appeared to be oxide-covered beryllium, but were found to be hollow on the tapered whiskers, and apparently are also hollow on the others. As an explanation of the method of growth the following is suggested. The beryllium vapor condenses forming a molten ball, the surface of which then oxidzes. At the interface between the ball and the substrate, oxidation is assumed to occur in such a manner, perhaps by the formation of a screw dislocation, as to promote the growth of an oxide whisker which pushes the ball away from the container. The growth takes place at the ball-whisker junction utilizing beryllium from the ball and oxygen from the water in the wet atmosphere. As the beryllium is used from the sphere, the sphere is prevented from collapsing by the oxide on its surface. It is possible in this way to account for the empty sphere at the top of the whiskers.

NA12. Three-Dimensional Extension of Houston's Method for Face-Centered Cubic Crystals.* D. D. BETTS, *The University of Alberta.*—Houston's method of integration of functions of rotational symmetry O_h over the surface of a sphere utilizes the fact that the integrand can be expanded in an orthogonal set of Bethe's Kubic Harmonics having the same symmetry. Of more interest is the problem of integrating functions having both the rotational and translational symmetry of a crystalline space group over a three-dimensional Brillouin zone or cellular polyhedron. In order to develop a Houston-type formula utilizing both types of symmetry, we define as face-centered cubic harmonics, $F_l(x,y,z)$, polynominals in x, y, and z belonging to the identity representation of the cubic rotation group, and whose normal derivative vanishes over the faces of the rhombohedral dodecahedron, which is the cellular polyhedron in face-centered cubic crystals, It is not necessary to completely orthogonalize the F_l to one another, but only to $F_0 = 1$. The conditions on the F_l are so stringent that F_l is of degree twelve in x, y and z. An integration formula will be presented using the first fourteen face-centered cubic harmonics to derive the weights for the integrand at fourteen symmetrically arranged points in one forty-eighth of the cellular polyhedron.

* Supported by the National Research Council of Canada.

FRIDAY MORNING AT 9:30

New Yorker Boston Room

(M. L. GOLDBERGER presiding)

Theoretical Physics IV: Dispersion and Spectral Theory

O1. Quantized Meson Field in a Classical Gravitational Field.* TSUTOMU IMAMURA,† *University of North Carolina.*—The behavior of a quantized meson field in a classical gravitational field is examined. Physical quantities such as the expectation value for the number of created mesons are represented in terms of a formal Green's function. The sole requirement imposed is that the gravitational field be such that well defined state vectors exist in the remote past and future. They are computed explicitly for the follwoing space independent gravitational field: The metric tensor is Minkowskian for $t>\tau+L^{-1}$ and $t<-\tau-L^{-1}$, constant for $\tau>t>-\tau$, and suddenly switched on and off in the regions $-\tau>t>-\tau-L^{-1}$ and $\tau+L^{-1}>t>\tau$. Inadequacy of standard iteration procedures is discussed.

* Work supported by U. S. Air Force Office of Scientific Research.
† On leave of absence from Osaka University.

O2. Coulomb Correction in Nucleon-Nucleon Dispersion Relation.* D. Y. WONG, *Lawrence Radiation Laboratory, Berkeley,* AND H. P. NOYES, *Lawrence Radiation Laboratory, Livermore.*—The p-p, s-wave nonrelativistic dispersion relation is formulated with specific attention to the Coulomb effect. Only the long-range part (one-meson exchange) of the nuclear force is treated exactly. Shorter range forces are implicit in the subtraction constants: (a) the Schrödinger equation with a repulsive Couiomb potential plus an attractive Yukawa potential is considered. (b) The Schwinger function $[C^2q\cot\delta-e^2Q]$ is shown to be analytic in q^2 except for $q^2\leq-\mu^2/4$, on the real axis. δ is the "nuclear" phase shift and μ is the pion mass. (c) $[(1/C^2q)e^{i\delta}\sin\delta]$ is calcualted exactly in the Born approximation (first power in pion-nucleon coupling constant). (d) A dispersion relation is written down with the scattering length and the effective range as two subtraction constants. (e) An iterative scheme is formulated to calculate the Schwinger function in terms of the Born approximation and the subtraction constants. (f) From the Schwinger function, we calculate $[(1/q)e^{i\delta}\sin\delta]$ for $q^2<-\mu^2/4$. It has a pole at $q^2\sim-2\mu^2$, representing the average effect of the shorter-range forces. The position and residue of this pole are compared with corresponding parameters in the singlet n-p problem[1] since δ should be very close to the actual phase shift caused by the nuclear force alone in such a region.

* This work done under the auspices of the U. S. Atomic Energy Commission.
[1] H. P. Noyes and D. Y. Wong, Phys. Rev. Letters 3, 191 (1959).

O3. Dispersion Relations for Mass Renormalization Constants.* PAUL DECELLES AND GORDON FELDMAN, *The Johns Hopkins University.*—The wave function renormalization constant and the mass renormalization in the Lee Model have been calculated exactly using dispersion relation techniques.[1] The results agree with those obtained by solving the eigenvalue problem directly. The same techniques are applied to the calculation of the self-energy of the electron. We approximate the spectral functions ρ_1 and ρ_2[2] by including only contributions from two intermediate states, the single electron state and the interacting electron-photon state. The contributions to the ρ_i from the matrix $\langle e\gamma|\bar{\psi}|0\rangle$ are determined as follows. Form factors are defined for a representation of the matrix element $\langle e\gamma|\bar{\psi}|0\rangle$. We determine a set of coupled singular integral equations for these form factors, which is solved with certain approximations. The comparison with perturbation theory and the approximations made in the calculation will be discussed.

* Supported in part by the National Science Foundation.
[1] P. DeCelles and G. Feldman, Nuclear Phys. (to be published).
[2] H. Lehmann, Nuovo cimento 11, 342 (1954).

O4. Application of Dispersion Relations to Pion-Hyperon Production.* RICHARD H. CAPPS, *Cornell University.*—The dispersion relations for pion-hyperon scattering and for the pi-hyperon production processes $\bar{K}+N\rightarrow\pi+\Sigma$ (or Λ) are studied in the static limit, in order to illuminate the connection between these processes. All real states of more than two particles or orbital angular momentum greater than one are neglected. If the crossed terms in the dispersion relations were small and the K coupling were weak, the production amplitudes would be approximately proportional to the corresponding scattering amplitudes (except for certain known kinematical factors). These proportionality relations would be analogous to those between photo-pion production and pion-nucleon scattering. Any resonance in the isotopic spin 0 or 1 pi-hyperon scattering at an energy above the $\bar{K}$-N threshold would also be present in the corresponding pi-hyperon production process. An estimate is made of the corrections to the proportionality relations that result from the moderately strong K coupling, and from the "crossed" production processes $\pi+N\rightarrow K+Y$. The behavior of the various amplitudes in the global symmetry model is discussed.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

O5. Electromagnetic Structure of the Nucleon.* ADAM M. BINCER, *University of California, Berkeley.*—Dispersion relations are proved for the nucleon electromagnetic form factors considered as a function of nucleon mass. In contrast to earlier treatments using dispersion relation techniques, it is possible in this way to study both the isotopic scalar and the isotopic vector parts of the electromagnetic structure of the nucleon. The results are used to express the nucleon form factors in terms of pion electroproduction (or photoproduction) amplitudes and pion-nucleon scattering phase shifts in the $J=\frac{1}{2}$, $T=\frac{1}{2}$ state.

* Research supported by the U. S. Air Force Office of Scientific Research.

O6. Spectral Representations for Large Momentum Transfer in Perturbation Theory.* R. KARPLUS AND J. TARSKI, *University of California, Berkeley.*—Spectral representations, or dispersion relations, are discussed within the framework of perturbation theory. In case of the fourth order, a detailed analysis of the amplitude as a function of two complex invariants can be applied advantageously. If there are no anomalous thresholds,[1] then the singularities which are associated with Mandelstam's spectral functions[2] do not prevent the analytic continuation of spectral representations to arbitrarily large space-like momentum transfers. If there are anomalous thresholds then spectral representations are valid for space-like momentum transfers except possibly for a finite interval of the momentum transfer variable, but only limited analytic continuation in momentum transfer is possible.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] Karplus, Sommerfield, and Wichmann, Phys. Rev. 114, 376 (1959).
[2] S. Mandelstam, Phys. Rev. 112, 1344 (1958).

O7. Feynman Amplitudes as Functions of Masses.* T. KINOSHITA, *Cornell University.*—After integration with respect to internal momenta, Feynman amplitudes can be considered as functions of masses that appear in the propagators. Property of these functions is determined to a large extent by their singularities at the origin of mass variables. In general, the singularities can be classified into two types: (a) Singularities that occur when one mass variable vanishes; (b) Those that are found when masses of three propagators connecting a 3-vertex part to the rest of the diagram vanish simultaneously. A typical example of (a) is the infrared divergence. Examples of (b) are divergences of radiative corrections of various processes, which appear at the origins of mass variables of some charged particles. Although (b) occurs for an unphysical value of mass, knowledge of its behavior is very useful in understanding the property of Feynman amplitudes. It is shown in particular that divergences of the type (b) show strong cancellation (although not complete in general) in the total cross section, quite analogous to the cancellation of infrared divergences. This holds to any order of perturbation theory. Some physical applications will be discussed.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

O8. Chew-Mandelstam Approximation and Other Approximation Procedures in Potential Scattering.* J. D. BJORKEN AND A. GOLDBERG, *Stanford University.*—Various approximation procedures fashionable in field-theoretic circles are tested in the special case of s-wave scattering by an exponential potential. In particular, for this case, the Chew-Mandelstam procedure of implementing the Mandelstam representation[1] can be carried out analytically in any order of approximation. We consider, (1) Chew-Mandelstam procedure, (2) the Fredholm (determinantal) expansion, expansions of (3) $\tan\delta$ (4) $\cot\delta$, and (5) $e^{i\delta}\sin\delta$ in power series in the potential strength, each in the first and second order of approximation. The results, expressed in terms of formulas for $k\cot\delta$, are compared with the exact solution, which may be obtained analytically in terms of Bessel functions of imaginary order. Numerical results will be discussed. Preliminary computations indicate that the Chew-Mandelstam procedure is perhaps comparable in accuracy to the Fredholm expansion. All of the approximation procedures (in second order) give at best qualitative agreement for values of the potential strength strong enough to produce bound states.

* Supported in part by the U. S. Air Force through the U. S. Air Force Office of Scientific Research.
[1] G. F. Chew and S. Mandelstam, University of California Report No. UCRL-8728, April 15, 1959 (not to be published).

O9. Some Rigorous Analytic Properties of Transition Amplitudes.* S. MANDELSTAM, *University of California, Berkeley.*—Some of the analytic properties of transition amplitudes as a function of two variables are proved from the causality and mass-spectral conditions. While the complete double-dispersion representation cannot be proved from these postulates alone, it is shown that, within a certain domain in the space of two complex variables, the only singularities are the expected poles and cuts along the real axes. This domain includes the low-energy physical region. The proof is restricted to the scattering of the lightest particles in the theory. One can then extend the domain of analyticity by the unitarity condition. The magnitude of this extention is not very large, but the new domain includes some of the region in which the two-dimensional spectral functions, associated with the double dispersion representation are nonzero. We only use the unitarity condition below the threshold for inelastic processes; if such processes could also be treated and the unitarity condition used at higher energies, it appears possible that the domain could be extended arbitrarily far. The present results are sufficient to justify the analytic properties assumed in the current calculations on pion-pion scattering.

* Supported in part by the U. S. Air Force Office of Scientific Research.

O10. K^+-K^0 Mass difference in Local Field Theory.* GRAHAM FRYE, *University of California, Berkeley.*—It has been suggested that the negative sign of the K^+-K^0 mass difference can be attributed to a distribution of charge in the K^0. If the electromagnetic form factor is decomposed into (normalized) isotopic scalar and vector parts, the mass difference depends on their product. To obtain the observed *sign*, the product must change sign and remain negative over a substantial range of momentum transfer. Unitarity and the Mandelstam representation are used to express the spectral function of the vector part as a product of the pion electromagnetic form factor and the matrix element for $\pi+\pi\rightarrow K+\bar{K}$. The proposed resonance in π-π scattering[1] suggests that the vector spectral function is very large at low frequencies and may therefore change sign at higher frequencies. We attempt to derive such a behavior by relating the vector spectral function to the π-K scattering amplitude. It appears that a p-wave resonance in both isotopic spin $\frac{1}{2}$ and $\frac{3}{2}$ channels is needed.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] W. R. Frazer and J. R. Fulco, Phys. Rev. Letters **2**, 365 (1959).

O11. Conserved Currents and Muon Polarization in $K_{\mu 3}$ Decay.* S. HATSUKADE, R. E. MARSHAK, S. OKUBO, AND E. C. G. SUDARSHAN, *University of Rochester.*—In both $\pi_{\mu 2}$ and $K_{\mu 2}$ decays, conservation of linear and angular momentum requires that the longitudinal polarization of the muon is complete and of the same sign as that of the neutrino; but in $K_{\mu 3}$ decay, $K\rightarrow\pi+\mu+\nu$ this restriction is relaxed. Under the hypothesis of a conserved strangeness-violating vector current, we have investigated the variation (in sign and magnitude) of the muon polarization with the parameters fixing the decay configuration; the latter is essentially specified by the pion and muon energies. From kinematic considerations it may be shown that, for a given muon energy, the longitudinal polarization of the muon varies from complete polarization of one sign (negative for μ^-) to complete polarization of the opposite sign when the pion energy changes from its maximum value to its minimum value. The "conserved current" hypothesis fixes the variation between these limits. The results will be compared with the consequences of other assumptions regarding the decay interaction (e.g., constancy of the form factors[1]).

* Supported in part by the U. S. Atomic Energy Commission.
[1] S. G. Matinyan and L. B. Okun, Soviet Phys. JETP, **36**, 933 (1959).

O12. Form of the Strangeness-Nonconserving Weak Interaction Current. L. WOLFENSTEIN, *Carnegie Institute of Technology.*—A possible explanation of the absence of $\mu\rightarrow e+\gamma$ decay is that the neutrino associated with the mu meson is different from that associated with the electron.[1] The weak interaction current then contains the particle pairs $(e\nu)$, $(\mu\nu')$, and (np); we now postulate that each particle field enters the current only once so that the remaining terms are (Ξ^-A^0), $(\Xi^0\Sigma^+)$, and (Σ^-B^0), where A^0 and B^0 are orthongonal fields made from Σ^0 and Λ^0. In particular, all strangeness-nonconserving weak interactions involve the Ξ particle. If we assume a universal coupling constant, no dilemma arises about the small rate of Λ and Σ leptonic decays since these no longer can occur in a direct manner. The simplest diagrams possibly giving appreciable Λ and Σ leptonic decays are those associated with virtual Ke_3 and $K_{\mu 3}$ decays. These are diagrams which previously have been considered as virtual meson corrections to the direct decay diagram. They are hard to calculate, but are distinguishable from the direct diagram in the predictions

of decay asymmetries, angular correlations, etc. Choosing Λ^0 as Σ^0 (B^0 as Λ^0), we find that in the decay $K^- \to \mu^- + \nu$ there is a destructive interference between virtual Ξ^-, anti-Σ^0 pairs and Ξ^0, anti-Σ^+ pairs which decreases the decay rate by a factor of about 18.

[1] S. A. Bludman, Bull. Am. Phys. Soc. Ser. II, 4, 80 (1959).

O13. Mechanisms for Λ Decay. DAVID HARRINGTON, *Carnegie Institute of Technology* (introduced by L. Wolfenstein).—Assuming a matrix element $j_\mu \bar{u}_e \gamma_\mu (1+\gamma_5) u_\nu$ for Λ β decay, with $j_\mu = \bar{u}_p [a\gamma_\mu + a'\gamma_\mu\gamma_5 + ib\sigma_{\mu\nu}(p_\Lambda - p)_\nu + ib'\gamma_5\sigma_{\mu\nu}(p_\Lambda - p)_\nu] u_\Lambda$, the low rate[1] of the process imposes limits on the constants a, a', b and b'. In particular, if one assumes $a \approx a'$, rough calculations indicate that $|a|^2$ can be at most one half or one third of the square at the "universal" coupling constant. It has been suggested[2] that a matrix element of the form $j_\mu p_{\pi\mu} f$ is mainly responsible for $\Lambda \to p + \pi^-$, i.e. that the contribution of terms corresponding to diagrams in which mesons "bridge" the weak interaction is negligible. For this decay, the tensor terms do not contribute and the experimental asymmetry requires a $\approx a'$. The upper limits on $|a|^2$ given by Λ β decay then restrict the decay rate to be several times smaller than the experimental value, if one takes the f from the $\pi \to \mu + \nu$ rate.[3] It thus appears that diagrams of the suggested type cannot be the primary mechanism in $\Lambda \to p + \pi^-$.

[1] Nordin *et al.*, Phys. Rev. Letters 1, 380 (1958).
[2] Okubo, Marshak, and Sudarshan, Phys. Rev. 113, 944 (1959).
[3] S. B. Treiman, Proceedings of 1958 Annual International Conference on High Energy Physics at CERN; p. 276.

FRIDAY MORNING AT 9:45

Statler Hilton Skytop Room

(N. KROLL presiding)

Invited Papers in Theoretical Physics

OA1. Nuclear Forces and Properties of Nuclear Matter. S. A. MOSZKOWSKI, *University of California, Berkeley.* (30 min.)

OA2. New Approach to Nucleon-Nucleon Scattering. MICHAEL J. MORAVCSIK, *University of California, Berkeley.* (30 min.)

OA3. Nuclear Structure Effects on Internal Conversion. JOSEPH WENESER, *Brookhaven National Laboratory.* (30 min.)

OA4. The Asymmetric Nucleus. D. M. VAN PATTER, *Bartol Research Foundation.* (30 min.)

FRIDAY MORNING AT 9:45

Statler-Hilton Grand Ballroom

(W. K. H. PANOFSKY presiding)

Equipment Ancillary to Accelerators

P1. Recent Developments in Scintillation-Chamber Techniques. G. T. REYNOLDS, *Princeton University.* (30 min.)

P2. Problems and Techniques in the Analysis of Bubble-Chamber Photographs. HUGH BRADNER, *University of California, Berkeley.* (30 min.)

P3. Focusing and Separation of Beams from Accelerators. E. D. COURANT, *Brookhaven National Laboratory.* (30 min.)

P4. Recent Advances in Electronic Instrumentation in High-Energy Physics. V. L. FITCH, *Princeton University.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Statler-Hilton Grand Ballroom

(L. J. HAWORTH presiding)

Accelerators

PA1. Experimental Use of Multi-Bev Accelerators. W. K. H. PANOFSKY, *Stanford University.* (30 min.)

PA2. Some Problems in Planning for Future High-Energy Proton Accelerators. D. L. JUDD, *University of California, Berkeley.* (30 min.)

PA3. Experimental Methods for Use with Colliding Beams. G. K. O'NEILL, *Stanford University.* (30 min.)

PA4. Plasma Betatrons and Relativistic Plasma Physics. K. C. ROGERS, *Stevens Institute of Technology.* (30 min.)

FRIDAY AFTERNOON AT 2:00

New Yorker Boston Room

(E. P. WIGNER presiding)

Invited Paper

Q1. Quantum Theory of Gravitation. S. N. GUPTA, *Wayne State University.* (30 min.)

Relativity; Baryon Interactions

Q2. Renormalization Effects in an Expanding Universe. F. L. SCARF, *University of Washington.*—The equations of quantum electrodynamics are investigated in an expanding universe characterized by a de Sitter metric. It is assumed that the expansion occurs on a microscopic level, and that $\hbar$, the bare electron mass, and the bare charge are all constant. For a particular coordinate system, the operators may be expressed in terms of coupled flat-space fields which have m replaced by $mR(t)$. The equivalent quantized field problem is soluble using standard perturbation theory with modified commutators and Green's functions. As a first approximation, adiabatic changes caused by the expansion are evaluated by making the replacement $m \rightarrow mR$ in all final formulas. Renormalization effects are examined using asymptotic expressions which contain ultraviolet cut offs. Assuming that the cutoff procedures are meaningful and are related to the structure of the physical electron, it is noted that the renormalized mass and charge may vary with time.

Q3. Influence of Gravitational Radiation Reaction on the Motion of Two Bodies.* STANLEY F. SMITH AND PETER HAVAS, *Lehigh University.*—A systematic approximation method for obtaining the general relativistic equations of motion for simple poles of the gravitational field has been reported earlier.[1] The resulting Lorentz-invariant equations are used to investigate the motion of two bodies with retarded interaction. Two equal masses undergoing almost circular motion are found to spiral outward (rather than inward as in the corresponding problem of electrodynamics). For any reasonable definition of the mechanical energy of the two-body system, this corresponds to an energy gain. While the outward spiraling is all the information concerning gravtiational radiation obtainable from a consideration of the equations of motion alone, it is found that gravitational field energy can be defined so as to furnish an "influx of energy" from infinity in quantitative agreement with the "energy gain" of the two-body system calculated from the motion. Some implications of these results are discussed.

* Supported in part by the National Science Foundation.

[1] P. Havas, Phys. Rev. **108**, 1351 (1957); P. Havas and J. N. Goldberg, (to be published).

Q4. Remarks on the Canonical Formulation of General Relativity.* J. C. GARRISON AND F. J. BELINFANTE, *Purdue University.*—In the canonical formulation of general relativity recently obtained by Arnowitt, Deser, and Misner (to be published), a nonvanishing energy-density tensor $T_\mu{}^\nu$ is introduced. In order to see whether this quantity can be used in the Schrödinger equation, we must verify that it satisfies the appropriate integrability condition. For this purpose, we must calculate the commutators $[T_\mu{}^\nu(x); T_\sigma{}^\beta(x')]$ on the initial space-like surface. The $T_\mu{}^\nu$ are not known explicitly as functions of the cannonical variables, but we can calculate the commutators by use of the constraints. Generalizing this theory, we consider a model of matter-gravity interaction in which the matter is represented by a neutral scalar field. In this case, the canonical formalism can be obtained as before. In the more realistic case of the interaction of gravity with a fermion field, the situation is complicated by the presence of derivatives of the gravitational field in the matter part of the Lagrangian. Another problem to be investigated is the possibility of obtaining an interaction picture from some properly defined interaction part of $T_\mu{}^\nu$.

* Supported in part by the National Science Foundation.

Q5. First-Order Hamiltonian for the Gravitational Field in Interaction with a Scalar and a Spinor Field.* JAMES L. ANDERSON AND SAMUEL SCHIMINOVICH, *Stevens Institute of Technology.*—The Hamiltonian for a gravitational field in interaction with a scalar and a spinor matter field is obtained to first order approximation, in terms of two independent components of the metric tensor. The constraint equations together with the resultant coordinate conditions are used to eliminate the other eight degrees of freedom of the metric field according to a method developed by one of us.[1] This elimination leads to the appearance in the Hamiltonian of self-interaction terms for the matter fields analogous to the Coulomb-type interactions which arise in electromagnetic theory. The first order coordinate conditions, which follow directly from the choice of independent variables used to describe the gravitational field, are also given.

* Work supported by U. S. Air Force, Wright Air Development Center.

[1] J. L. Anderson, Proceedings of the Royaumont Conference on General Relativity.

Q6. Observables and Geometric Structure in General Relativity.* PETER G. BERGMANN AND ARTHUR B. KOMAR, *Syracuse University.*—It is now generally assumed that Riemannian manifolds satisfying the field equations of general relativity can be identified uniquely and invariantly by a complete, but non-redundant set of "observables," and that such a set numbers four per point of some three-dimensional space-like hypersurface, within the four-dimensional manifold. We should like to point out that these observables identify only the solution as a whole, but that knowledge of their numerical values is insufficient to determine all geometric characteristics of the manifold in the neighborhood of a world point, which is identified in terms of conventional coordinates. This is because the observables give no information as to the location of a given world point within its manifold; such information may be provided by means of "intrinsic coordinates," which are also invariant quantities but in a very different sense than the observables. If we know the observables characterizing a solution of the field equations and also the intrinsic coordinates of a world point, then all geometric properties at that point are fully determined.

* Supported by the National Science Foundation and by the Wright Air Development Center.

Q7. Possible Relations Among the Meson-Baryon Coupling Constants.* D. B. LICHTENBERG, *Michigan State University.*—Some consequences of various relations among the pion-baryon and K-baryon coupling constants are considered in perturbation theory. In particular, it is assumed that the magnitudes,

but not necessarily the signs, of all the pion-baryon coupling constants are equal, and similarly for the K-baryon coupling constants. It is further assumed that in the absence of these couplings, all the baryons would have the same mass. It is found that if global symmetry holds ($G_{\pi NN}=G_{\pi\Lambda\Sigma}=G_{\pi\Sigma\Sigma}=G_{\pi\Xi\Xi}$), then either of the following relations among the K-baryon couplings will remove the degeneracy in fourth order: $G_{K\Lambda N}=G_{K\Sigma N}=G_{K\Lambda\Xi}=-G_{K\Sigma\Xi}$ or $-G_{K\Lambda N}=G_{K\Sigma N}=G_{K\Lambda\Xi}=G_{K\Sigma\Xi}$. As far as is known, these relations do not contradict any experiment.[1] Other sign combinations either lead essentially to no new results, or do not completely remove the degeneracy. On the other hand, if cosmic symmetry holds ($G_{K\Lambda N}=G_{K\Sigma N}=G_{K\Lambda\Xi}=G_{K\Sigma\Xi}$), then no choice of signs among the pion-baryon couplings completely removes the degeneracy in fourth order.

* Work supported in part by the National Science Foundation.
[1] A. Pais, Phys. Rev. 110, 574 (1958), has shown that certain sign combinations are incompatible with experiment.

Q8. Interpretation of K Meson Experiments in Terms of Yukawa Interactions. ROBERT L. WARNOCK, *Harvard University.**—Some meson-baryon interaction schemes have been investigated by means of Heitler's unitary approximation, with an exact solution of the integral equation relating T and K. The solution of the integral equation is accomplished through relativistic angular momentum expansions of the matrix elements involved. K is computed both by the simple perturbation method and by a determinantal method which is presumably more accurate. Assuming a pion-baryon interaction with global symmetry and K interactions with lower symmetry, one may arrive at a fairly good description of the low and medium energy K_--p and K_+-p experiments. A particular theory (involving pseudoscalar K couplings with one coupling constant determined from K_+-p scattering) yields complex scattering lengths for the K_- case close to one of the two satisfactory sets determined from the experiments by Dalitz and Tuan. The determinantal approximation, which yields correctly the $J=\frac{3}{2}$, $T=\frac{3}{2}$ resonance when applied to pion-nucleon scattering, also may give a resonance in the $J=\frac{3}{2}$, $T=0$ amplitude for K_+-nucleon scattering at present laboratory energies. The possibility of associating such a resonance with the observed sharp rise in charge exchange events will be discussed.

* Now at Boston University.

Q9. Strong Interactions and a Model for Hyperons.* I. GOLDBERG, *University of Michigan*, AND LEON F. LANDOVITZ, *Brookhaven National Laboratory.*—A general formalism for the strong interactions under the assumption of equal coupling for Σ and Λ is presented. The interactions used are not in disagreement with experiment nor do they make any specific assumption about parities. The interactions are then used as a basis of a Goldhaber type model for the hyperons where the Λ, Σ, Ξ particles arise as bound states of the K, nucleon system. If the parameter is adjusted to give the correct nucleon, Λ mass splitting, the masses of Σ and Ξ are predicted.

* Research supported in part by the U. S. Atomic Energy Commission and Office of Naval Research.

Q10. Combined Inversion, Permutation Symmetry and Parity Conservation in Strong Interactions.* K. BARDAKCI, R. E. MARSHAK, AND E. C. G. SUDARSHAN, *University of Rochester.*—Since all known interactions of elementary particles are invariant under combined inversion (CB), various authors have considered the possibility of deriving the conditions for separate P invariance. For strong interactions, it has been shown that charge symmetry leads to P invariance for nonderivative coupling of the pion to the baryon, but not for kaon-baryon coupling. This proof, has been re-examined with the following results. (1) For the observed degree of P invariance in strong interactions it is necessary to postulate "strict" charge symmetry although experimentally such a "strict" charge symmetry cannot easily be tested. (2) A pseudoscalar fermion mass term cannot enter a CP invariant theory. (3) Separate P invariance for nonderivative coupling of the kaon to the baryons can be assured by invoking a new type of permutation symmetry, e.g. in the ΛpK interaction invariance under the permutation $K^+ \rightleftarrows K^-$, $\Lambda \rightleftarrows p$. This permutation symmetry has additional consequences which will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.

Q11. Anomalous Magnetic Moments of Baryons in Static Cutoff Perturbation Theory. T. T. CROW AND W. G. HOLLADAY,* *Vanderbilt University.*—The nucleon magnetic moments have provided an important check on various theoretical proposals concerning the interactions of nucleons with other particles. It may be that baryon magnetic moments will play a similar role in determining the interactions of baryons with various particles. To obtain a first orientation on these moments, we use the static cutoff form of field theory and calculate the following contributions to the anomalous magnetic moments; second-order pion, second-order kaon, fourth-order pion, and fourth-order pion kaon cross terms. In order to calculate the fourth order pion kaon cross terms, we have formulated a renormalization program similar to that of Chew,[1] but in which the baryon mass difference is taken into account. For a baryon X, we choose a cutoff which is $5.5/6.7M_x$. We use $g_{\pi\pi}^2/4\pi=14$ and assume various values for the other coupling constants to calculate the above contributions. The contribution of the interaction currents has been calculated and is by no means negligible.

* Now on leave at the University of Wisconsin.
[1] G. F. Chew, Phys. Rev. 94, 1748 (1954).

FRIDAY AFTERNOON AT 2:00

New Yorker Terrace Room

(J. STEINBERGER presiding)

Invited Papers

QA1. Ions in Liquid Helium. K. R. ATKINS, *University of Pennsylvania.* (30 min.)

QA2. Experimental Test of Charge Independence. A. SACHS, *Columbia University.* (30 min.)

QA3. Production of Lambda and Sigma Antihyperons. JANICE BUTTON, *University of California, Berkeley.* (30 min.)

QA4. Diffraction Regeneration of θ_1 Particles. ORESTE PICCIONI, *Brookhaven National Laboratory.* (30 min.)

FRIDAY AFTERNOON AT 2:00

New Yorker Grand Ballroom

(A. R. HUTSON presiding)

Symposium of the Division of Electron Physics

Aspects of the Physical Electronics of Surfaces

R1. Electronic Phenomena in Alumina Silicate Ion Emitters. FRED M. JOHNSON, *RCA Laboratories.* (30 min.)

R2. Binding Energy and Mobility of Nitrogen Atoms on Tungsten Crystal Surfaces. PAUL KISLIUK, *Bell Telephone Laboratories.* (30 min.)

R3. Influence of Crystal Orientation on Secondary Electron Emission of Insulators. A. B. LAPONSKY, *GE Research Laboratory.* (30 min.)

R4. Variation of Secondary-Electron Emission from Single Crystals with Angle of Incidence. R. W. SOSHEA, *University of Minnesota.* (30 min.)

R5. Recent Developments in the Field of Sputtering. G. K. WEHNER, *General Mills, Inc.* (30 min.)

Business Meeting of the Division of Electron Physics

(to be convoked during Session R when the Chairman chooses)

FRIDAY AFTERNOON AT 2:15

Statler-Hilton Penn Top South

(D. M. VAN PATTER presiding)

Nuclear Reactions and Energy Levels II

RA1. Charged Particle Reactions Induced by Bombardment of C^{13} and Li^6 with 2 Mev Li^6 Ions. S. M. SHAFROTH, *Northwestern University, and Saclay, France.*—In order to study nuclear reaction mechanisms with lithium nuclei as projectiles the Saclay 2-Mev Van de Graaff has been converted to a lithium accelerator; and a multi-angle nuclear emulsion plate camera has been used to measure angular distributions of the charged particle reaction products. The main work so far has involved Li^6+C^{13}. Protons groups leading to the ground state the 1st, 2nd, and 4th excited states of O^{17} have been identified unambigously. Angular distributions for P_2 and P_4 are symmetric with respect to 90° c.m. A group which could be P_3 of d_0 (deuterons leading to the ground state of O^{16}) or any mixture of these two has a c.m. angular distribution which is isotropic to within 10%. Thus no evidence for stripping has been found to date. An attempt is being made to increase the energy of the Li^+ ions by stripping them after 400 kev of acceleration. Alphas leading to the N^{14} ground state have been identified against a background of low energy protons. This has been possible due to the use of Ilford fine grain L2 emulsions and special development of the plates. As a byproduct of this work protons from Li^6+Li^6 leading to the ground and first excited states of B^{11}, alphas leading to the ground state of Be^8 and probably 3 alpha decay of 29-Mev excited C^{12} nuclei have been observed.

RA2. Isotopic-Spin Impurities and the Lifetime of the 7.12-Mev State in O^{16}.* S. FALLIEROS, *Bartol Research Foundation,* AND WILLIAM M. MACDONALD, *University of Maryland.*—$T=1$ admixtures in both the ground and the 7.12 Mev excited state of O^{16} are calculated and their effect on the $E1$ transition matrix element is discussed. A particular combination of the configurations $(1s)^{-1}2s$ and $(1p)^{-1}2p$ representing out-of-phase monopole oscillations of the proton and neutron systems is found present in the ground state with an unusually large amplitude. This admixture has however a vanishing $E1$ matrix element with the excited state if the latter contains only configurations $(1p)^{-1}1d$, $(1p)^{-1}2s$ .This is a consequence of the simple $1s$ dependence of these states on the relative separation of the proton and neutron centers of mass. For similar reasons the excited state cannot be coupled by the Coulomb interaction to the $T=1$ state that represents a relative dipole vibration of the proton-neutron system. When all possible admixtures of the same type of excitation are included, a nonvanishing result is obtained only when the level splitting caused by the effective nuclear interactions is taken into account.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.

RA3. Alpha-Particle Spectra from the Bombardment of F^{19} by N^{14}. C. EUGENE HUNTING, *Oak Ridge National Laboratory.**—Alpha-particle spectra from reactions induced in F^{19} targets by approximately 27.5-Mev N^{14} ions were observed at six laboratory angles from 35° to 105° by means of a proportional counter-scintillation counter telescope. Assuming the reaction $F^{19}(N^{14},\alpha)Si^{29}$, the alpha-particle energies observed correspond to excitation energies in the residual nucleus of approximately 8 to 28 Mev, out of a possible 37 Mev. Due to the low kinetic energies involved (less than 0.7 Mev per nucleon in the center-of-mass system prior to the collision) it is expected that there might be a statistical distribution of energy in the compound system. Analyses of the data in terms of a simple statistical model will be presented.

* Operated for U. S. Atomic Energy Commission by Union Carbide Corporation.

RA4. States of Low Excitation in Ne^{20}.* R. E. Benenson,† H. Y. Chen, and L. J. Lidofsky, *Columbia University.*—The five highest energy neutron groups from the $F^{19}(d,n)$ reaction were studied at laboratory system angles of 0°, 18°, 36°, 60°, and 90° using deuteron energy $\bar{E}d=3.57$ Mev. Four hundred μ thick Ilford C-2 emulsions were employed as detectors because of the serious energy resolution problem. Groups corresponding to neutrons leaving Ne^{20} in its ground, 1.63, 4.25, 4.97, and 5.63 Mev states appeared at the correct positions as calculated from the published range-energy curves. The 1.63 Mev level group is at least three times as intense as the ground state group and shows a clear $l_p=2$ stripping distribution. The ground state reaction does not appear to proceed by ordinary stripping. The 4.25-Mev level corresponds to either $l_p=2$ or $l_p=3$; the 4.96 level can tentatively be fit by an $l_p=1$ assignment based on the indication that the 18° point lies above the others, just cutside probable errors. The 5.63-Mev state angular distribution is almost isotropic within the uncertainties. The better stripping pattern obtained from the 1.63-Mev state group than higher or lower states suggests its description by a single particle picture. Scanning is continuing on the 18° plate.

* This work partially supported by the U. S. Atomic Energy Commission
† Permanent address: City College of New York.

RA5. Neutron-Gamma Ray Angular Correlations from $Mg^{26}(\alpha,n\gamma)Si^{29}$. G. J. McCallum* and A. E. Litherland, *Chalk River Laboratories, Canada.*—The $Mg^{26}(\alpha,n\gamma)Si^{29}$ reaction has been used to illustrate the simplifications introduced in the interpretation of triple angular-correlation measurements by choosing a target and bombarding particle of zero spin and by observing the neutrons in a counter fixed at 0° to the incident beam direction. In this case the angular correlations of the gamma rays with respect to the incident beam depend only on the properties of the final states in the residual nucleus.[1] Angular correlations of gamma rays in coincidence with neutrons were measured at alpha-particle energies of 4.74 and 4.94 Mev. Gamma rays from levels in Si^{29} at 1.28, 2.03, and 2.43 Mev were observed and the angular correlation coefficients obtained. From these coefficients the $M1$-$E2$ mixing ratios of the 1.28- and 2.43-Mev gamma rays were found to be 0.25 ± 0.05 or -3.4 ± 0.5 and -0.26 ± 0.08 or -1.10 ± 0.16, respectively. The angular correlation of the $E2$ 2.03 Mev gamma ray was in good agreement with theory.[1]

* Seconded from Nuclear Sciences Institute, New Zealand.
[1] A. E. Litherland, Bull. Am. Phys. Soc. Ser. II, **4**, 58 (1959).

RA6. Resonances in $Si^{28}(p,\gamma)P^{29}$ for $0.3\leq E_p\leq 2.0$ Mev. J. W. Olness and J. L. Parker, *Aeronautical Research Laboratory* (introduced by W. J. Price).—The cross section for $Si^{28}(p,\gamma)P^{29}$ has been studied for proton energies $0.3\leq E_p\leq 2.0$ Mev by bombardment of targets of both natural silicon and silicon enriched in the isotope Si^{28}. Resonances attributable to proton capture by Si^{28} were observed at 1.65 and 0.372 Mev. The capture cross section shows no evidence for a level reported[1,2] from the (p,p) and (d,n) reactions at $E_{ex}\sim 3.7$ Mev. The gamma spectrum obtained at the 1.65 Mev resonance, which has been studied previously,[1] shows only a ground state transition, as reported by Newton. The spectrum at the 0.372-Mev resonance shows four gamma rays of energy 1.372, 1.720, 1.140, and 1.949 Mev. From the measured intensities, and the work reported[1] from $Si^{28}(d,n)P^{29}$, it is suggested that the gamma rays arise as the decay of the resonance level at $E_{ex}=3.083$ Mev through levels at 1.949 and 1.372 Mev. There was no observable evidence for a direct ground state transition. (All energies given here are ± 12 kev.) Preliminary measurements at 0.372 Mev indicate that the angular distribution of the 1.949-Mev gamma ray involves $P_4(\cos\theta)$; the remainder exhibit at least a $P_2(\cos\theta)$ dependence. This limits the total angular momentum of the 3.083- and 1.949-Mev levels to $j\geq\frac{5}{2}$, and that of the 1.372 to $j\geq\frac{3}{2}$. Further measurements on angular distributions and branching ratios will be presented.

[1] P. M. Endt and C. M. Braams, Revs. Modern Phys. **29**, 683 (1957).
[2] Rubin, Bailey, and Passell, Phys. Rev. **114**, 1110 (1959).

RA7. Interference Effects in Stripping. J. A. Kuehner, E. Almqvist, and D. A. Bromley, *Chalk River Laboratories.*—Differential excitation functions have been measured for the proton groups leading to the ground and first two excited states of Si^{29} in the $Si^{28}(dp)Si^{29}$ reaction for $\theta_p=35°$ and 90° and for $6\leq E_d\leq 10.8$ Mev. Resonant structure appears in both the 35° and 90° data but is more pronounced off the stripping peak. Angular distributions of these proton groups have been obtained at 10 energies in this range of deuteron energies studied. In contrast to the differential excitation functions, the total excitation functions determined from these distributions are essentially independent of energy. The proton angular distributions show extrema at angles in accord with Butler[1] predictions, using an interaction radius of 6.6 f, however, the envelope of the maxima does not decrease with angle as predicted by the usual deuteron form factor. A constant form factor does provide an acceptable fit to the data for both the $l_n=0$ and $l_n=2$ cases over the 20° to 150° angular range. These data are interpreted as reflecting direct interaction compound system interference effects but with a dominant direct reaction amplitude.

[1] S. T. Butler, Proc. Roy. Soc. (London) **A208**, 559 (1951).

RA8. Distorted Wave Effects in Stripping. D. A. Bromley, J. A. Kuehner, and E. Almqvist, *Chalk River Laboratories.*—p,γ angular correlations have been measured in the $\mathbf{k_d}\times\mathbf{k_p}$ plane for the $Si^{28}(d,p\gamma)Si^{29}$ reaction populating the first and second excited states of Si^{29}. In both of these cases measurements were carried out with the protons detected on the peak of the $l_n=2$ angular distributions. By using a thin (120 kev) SiO_2 target the observed correlations at 9.0, 8.6, and 8.0 Mev are well represented by the plane wave stripping prediction but with an attenuation of 25% and with a small shift of the symmetry axis from the nuclear recoil axis. In this energy range, for the $\frac{5}{2}+$ second excited state this shift increases monotonically with energy from $(2\pm2)°$ to $(8\pm3)°$ and is away from the incident deuteron direction. For the $\frac{3}{2}+$ first excited state the shift has roughly twice the magnitude and the opposite sign. These data are in qualitative agreement with distorted wave stripping theory.[1] At $E_d=6$ and 7 Mev the thin target angular correlations showed considerable deviation from the plane wave prediction. Correlations obtained using a thicker target (600 kev) at $E_d=7.0$ and 8.0 Mev are in agreement with the higher energy thin target results; these measurements support an interference explanation for the anomalous 6 and 7 Mev correlations.

[1] Huby, Refai, and Satchler, Nuclear Phys. **9**, 94 (1958).

RA9. Gamma Rays from the Proton Bombardment of Silicon.*† A. C. L. Barnard, S. Bashkin, C. Broude,‡ and C. E. Hornback,§ *State University of Iowa.*—Thin targets of natural silicon and of silicon enriched in Si^{30} were bombarded with protons with energies between 1.1 and 4.2 Mev. Gamma-ray yield curves at 55° to the beam show about 80 resonances attributed to the reactions $Si^{30}(p,p'\gamma)Si^{30}$ and $Si^{30}(p,\gamma)P^{31}$, the largest resonance being at $E_p=3.88$ Mev. This resonance is observable with the natural silicon target and has previously been attributed to the reaction $Si^{28}(p,p'\gamma)P^{29}$. Gamma-ray spectra taken on the proton-capture resonances show complex cascading through the lower levels of P^{31}.

* Supported in part by the U. S. Atomic Energy Commission.
† Preliminary report: Broude, Bashkin and Hornback, Bull. Am. Phys. Soc. Ser. II, **3**, 381 (1958).
‡ Now at Atomic Energy of Canada, Ltd., Chalk River, Ontario.
§ Now at the Boulder Laboratories of the National Bureau of Standards.

RA10. Angular Distributions of Gamma Rays from $Si^{30}(p,p'\gamma)Si^{30}$.* C. BROUDE† AND A. C. L. BARNARD, *State University of Iowa*.—The angular distributions of 2.24 Mev gamma rays from the reaction $Si^{30}(p,p'\gamma)Si^{30}$ were measured at 11 resonances in the energy range $E_p = 3.1$ to 3.5 Mev. The presence of strong quadrupole terms in some of the distributions precludes a spin $J=0$ or 1 for the first excited state in Si^{30}. Calculations were made of the distribution of Si^{30*} among its magnetic substates necessary to give the observed angular distributions. For $J=2$ all substate populations were positive, whereas for $J=3$ some were negative. This state is therefore probably $J=2$ as expected. Spin-parity assignments can be made for some of the levels of the P^{31} compound nucleus.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Atomic Energy of Canada, Ltd., Chalk River, Ontario.

RA11. Cross Sections of the (γ,p) and (γ,pn) Reactions in A^{40}.* S. A. GOLDEN, D. J. ZAFFARANO, AND D. S. MARTIN, JR., *Iowa State University*.—The (γ,p) and (γ,pn) reactions in A^{40} have been studied to 43 Mev with hardened bremsstrahlung. The cross sections for these reactions were determined by the Penfold-Leiss method and have the following parameters:

	(γ,p)	(γ,pn)
E_{th}	13 Mev	19 Mev
E_{max}	23 Mev	25 Mev
$\sigma(E_{max})$	15 mb	1.3 mb
σ_{int} (to 43 Mev)	179 Mev-mb	9 Mev-mb

The result for the integrated (γ,p) cross section up to 28 Mev agrees well with the value obtained by Brix *et al.*,[1] but is about a fourth of that reported by Penfold and Garwin.[2] The most striking feature of the cross-section curves is the existence of a strong high-energy tail in both reactions. The experimental cross section for the (γ,p) reaction fits predictions made by the Wilkinson model[3] with respect to both shape (peak to tail ratio and width of the giant resonance) and integrated cross section.

* Work supported by the U. S. Atomic Energy Commission.
[1] Brix, Kording, and Lindenberger, *Z. Physik* **154**, 569 (1959).
[2] A. S. Penfold and E. L. Garwin, Phys. Rev. **114**, 1139 (1959).
[3] D. H. Wilkinson, Physica **22**, 1039 (1956).

FRIDAY AFTERNOON AT 2:00

Statler-Hilton Ivy Suite

(R. M. BOZORTH presiding)

Ferroelectricity and Magnetism

S1. Theory of the Electric Field Variation of Incremental Permittivity in Perovskite-Type Ferroelectrics.* HOWARD DIAMOND, *University of Michigan*.—A model is considered for the case of polycrystalline ferroelectrics in which each crystallite is presumed to behave according to Devonshire's free energy function.[1] The Curie temperatures for the individual grains are taken in a Gaussian distribution about some chosen temperature. The permittivity is obtained by averaging with this distribution over all of the crystallites. In accordance with the free energy function, it is assumed that the electric field induces a ferroelectric axis along the field direction in those crystallites of the distribution which are not ferroelectric at a given temperature. On the basis of experimental evidence, domains in the ferroelectric part of the distribution are presumed to be immobile. Despite the seemingly severe restriction imposedby the latter assumption, a large field sensitivity is predicted. Agreement between the theory and the experimental data is excellent for both parallel and transverse fields. It is concluded tha the variation of incremental premittivity is associated with an induced ferroelectric state rather than being directly a property of domain processes, and that a large variation with field must necessarily be accompanied by strong thermal sensitivity.

* Work supported jointly by the National Science Foundation and the U. S. Air Force Office of Scientific Research.
[1] Compare A. F. Devonshire, *Advances in Physics* (Taylor and Francis, Ltd., London, 1954), Vol. 3, p. 10.

S2. System $(Ba_{6-2x}R_{2x})(Nb_{9-x}Fe_{1-x})O_{30}$. I. Ferroelectric Properties. P. H. FANG, R. S. ROTH, AND H. S. SCHOFER, *National Bureau of Standards*.—Ferroelectric properties were found in the system $2BaNb_2O_6+P$, where P denotes materials with perovskite structures, such as $BaZrO_3$,[1] or hybrid perovskite, such as $Ba(Nb,Fe)O_3$.[2] We find P could also be one of the rare earth ferrites of perovskite structure. Compounds of the composition $(Ba_{6-2x}R_{2x})(Nb_{9-x}Fe_{1+x})O_{30}$ fall into this category. Ferroelectric and ferrimagnetic properties are found in the foregoing system where R is one of the rare earth ions, Nd, Sm, Eu, and Gd. Preliminary results were reported at the Fifth Symposium on Magnetism and Magnetic Materials, by Fang and Roth. The ferroelectric hysteresis loops were observed at room temperature for R = Gd, Eu, and Sm, and below room temperature for R = Nd. On heating and cooling the dielectric constant and the spontaneous polarization show large temperature hysteresis near the critical temperatures where the dielectric constant shows a maximum or the spontaneous polarization vanishes. For Gd, Eu, and Sm the critical temperatures are about 180 and 120°C. For Nd, they are about −5 and +70°C. When R = Gd and x varies from 0 to 1, there is an increase of the critical temperatures for heating from −160 to +170°C. The data indicate a single phase region in the system $BaNb_2O_6-Ba(Nb_{0.5},Fe_{0.5})O_3-GdFeO_3$ which has both ferroelectric and ferrimagnetic properties.

[1] R. S. Roth, Bull. Am. Phys. Soc. Ser. II, **4**, 63 (1959); Fang, Roth, and Brower, *ibid.* **4**, 64 (1959).
[2] Fang, Roth, and Johnson. J. Am. Ceram. Soc. (to be published).

S3. System $(Ba_{6-2x}R_{2x})(Nb_{9-x}Fe_{1-x})O_{30}$. II. Ferrimagnetic Properties. P. M. PAN, *Westinghouse Electric Corporation*, AND P. H. FANG AND R. S. ROTH, *National Bureau of Standards*.—Ferrimagnetic properties are found in the system where R is one of the trivalent rare earth ions. The Curie temperatures of these materials increase with the decrease of the ionic radius. The temperatures are, −30°C for Nd, 35°C for Sm, 60°C for Eu, and 90°C for Gd. Following are some data measured at the room temperature. Frequency dispersions of these materials in the ferrimagnetic state are in the region of 15 to 25 Mc. A dielectric dispersion is also found in the same frequency region at the room temperature. For Sm, Eu, and Gd the coercive field is about 900 oe measured at 455 kc. The intrinsic magnetic permeability is about 35 to 50 for R = Nd, Sm, Eu. For R = Gd, this value is 120. These compositions seem to represent a new ferrimagnetic structure.

S4. System $(Ba_{6-2x}R_{2x^{+3}})(Nb_{9-x}M_{1+x^{+3}})O_{30}$. III. Structural Data. R. S. ROTH AND P. H. FANG, *National Bureau of Standards.*—Compositions in this system will be described for the situation where $x=0$, i.e., there is no R component, and M is any trivalent ion. A single phase can be prepared for M varying in size from Mn through Yb. For Y, Ho, and Dy this structure type apparently is only metastable, while for the larger M ions the structure does not occur at all. When R^{+3} is one of the larger rare earth ions from La^{+3} to Gd^{+3}, M is Fe^{+3}, and x varies from 0 to 1, the tungsten bronze structure occurs and ferroelectric and ferrimagnetic properties are observed. The tetragonal potassium tungsten bronze structure[1] is based on a ratio of 6 large cations to 10 smaller (octahedrally coordinated) cations and 30 oxygen ions. The space group is $P4/mbm$ and contains 2 large ions and two small ions in twofold special positions 000, $\frac{1}{2}\frac{1}{2}0$ and $0\frac{1}{2}\frac{1}{2}$, $\frac{1}{2}0\frac{1}{2}$, respectively, while the remaining 4 large ions are in $x\frac{1}{2}+x0$ and the 8 smaller ions in $xy\frac{1}{2}$. It is suggested that the ferrimagnetic properties may arise from the rare earth and iron ions occupying the twofold special positions and the ferroelectric properties from the Ba and Nb ions occupying the remaining cation positions in the structure. This hypothesis will be evaluated by comparison of calculated and observed x-ray powder diffraction data.

[1] A. Magnoli, Arkiv Kemi **1**, 213 (1949).

S5. Resonance Spectrum of a Paramagnetic Ferroelectric: Cr^{+++} in Guanidine Alum. E. G. BROCK, E. I. HORMATS, AND F. C. UNTERLEITNER, *Stromberg-Carlson.*†—Electron paramagnetic resonance has been observed for low concentrations of guanidine chromium sulfate hexahydrate in isomorphous guanidine aluminum sulfate hexahydrate. Both materials are ferroelectric.[1] Single crystals used in the resonance measurements were prepared by crystallization from a saturated aqueous solution. The crystals grew in the form of hexagonal plates with the trigonal crystalline symmetry axis as the normal. Results obtained at room temperature using a TM_{010} mode reflection cavity at 9540 mcps on single crystals of $(CN_2H_6)Al_{0.99}Cr_{0.01}(SO_4)_2\cdot 6H_2O$ suggest an effective $\frac{1}{2}$ spin for the chromium ion. The principal magnetic axis coincides with the crystalline trigonal axis. No off-axis splitting is indicated. However, a distinctive pairing of all transitions suggests that the chromium ions occupy two magnetically dissimilar lattice sites, I and II. In terms of the usual spin Hamiltonian, $\mathcal{H}=\beta H\cdot g\cdot S+D[S_z^2-\frac{1}{3}S(S+1)]$, $g=g_{\rm I}=g_{\rm II}=1.98$ and is almost isotropic; while $|D_{\rm I}|=0.0720$ cm^{-1} and $|D_{\rm II}|=0.0575$ cm^{-1}. The crystal structure[1] [space group $C_{3v}(2)-P31m$, three molecules per unit cell] suggests Type I chromium is in a special position on the mirror plane and Type II chromium is in a general position. On this basis relative chromium populations should be I:II=1:2, in agreement with the observed resonance amplitude ratios.

† Research Division of the Stromberg-Carlson Division of General Dynamics Corporation, Rochester, New York.
[1] Holden, Merz, Remeika, and Matthias, Phys. Rev. **101**, 962 (1956).

S6. Spin-Phonon Interaction in Yttrium Iron Garnet. H. BÖMMEL AND K. DRANSFELD, *Bell Telephone Laboratories.*—We have measured the acoustic absorption in YIG at a frequency of 1000 Mc as a function of an applied dc magnetic field. The single-crystalline YIG specimens were round disks 0.120 in. diam, between 0.005 in. and 0.012 in. thick. Both the end faces were indium-bonded onto oriented AC-cut quartz rods for the propagation of transverse hypersonic waves[1] through the disk, in the direction normal to the plane of the disk. The dc magnetic field, also oriented normal to the disk, was varied up to 7000 gauss. The acoustic transmission through the disks showed an enormous decrease around the field for ferrimagnetic resonance corresponsing to an additional acoustic resonance absorption of several hundred db/cm. This absorption is temperature independent between 20° and 2°K. It does not occur for longitudinal sound waves or if the magnetic field is misaligned by more than 10° from its direction normal to the disk. The absorption possibly arises from the acoustic excitation of spinwaves having the same energy and momentum as the incident phonon.[2] More experiments are in progress to test this ideal.

[1] Technical details are described in another paper submitted to Phys. Rev.
[2] See, for example, C. Kittel, Phys. Rev. 110, 836 (1958).

S7. Line Width Narrowing in Gallium Substituted Yttrium Iron Garnet. E. G. SPENCER AND R. C. LECRAW, *Bell Telephone Laboratories.*—Ferromagnetic resonance line widths have been measured in single crystal yttrium iron garnet (YIG) in which some of the ferric ions have been replaced by nonmagnetic gallium ions. There is an almost complete preference of the gallium ions for the tetrahedral sites.[1] In spherical samples of YIG grown using the highly purified yttrium oxide,[2,3] the (full) line width, at 6000 Mcps and 300°K, $\Delta H=0.375$ oe and $4\pi M=1750$ gauss. For YIG-Ga of various concentrations of gallium $\Delta H=0.62$ when $4\pi M=1050$ and $\Delta H=1.2$ when $4\pi M=400$. The continued narrowness of these lines in the presence of large inhomogeneous fields due to missing ferric ions in the ordered sites is evidence for the effectiveness of exchange or dipolar narrowing. The temperature dependence is similar to previous data on YIG.[2] There is, however, a stronger frequency dependence.

[1] M. A. Gilleo and S. Geller, Phys. Rev. 110, 73 (1958).
[2] Spencer, LeCraw, and Clogston, Phys. Rev. Letters 3, 32 (1959).
[3] J. W. Nielsen, 1959 Conference on Magnetism and Magnetic Materials.

S8. Oscillations in the Thermomagnetic and Galvanomagnetic Effects in Tin at Low Temperatures.* J. M. REYNOLDS, K. S. BALAIN, AND C. G. GRENIER, *Louisiana State University.*—De Haas-van Alphen type oscillations have been observed in the Hall effect, Ettinghausen-Nernst effect, and thermoelectric power in tin. With the magnetic field parallel to the tetragonal axis, the period of the oscillations in $1/H$ is 5.7×10^{-7} gauss^{-1} for each effect (This is in good agreement with the periods reported by Alers[1] for oscillations in the electrical and thermal magnetoresistance.) The measuring apparatus was sufficiently sensitive that oscillations in each effect could be clearly seen at fields as low as 10 kilogauss. About one hundred oscillations were recorded in the range 10–17 kilogauss. Measurements made at several temperatures from 1.2°K to 4.2°K show the amplitude of the oscillations in each effect to be strongly dependent on temperature. An analysis of this dependence will be attempted.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] P. B. Alers, Phys. Rev. **107**, 959 (1957).

S9. Neutron Diffraction Study of the Magnetic Structure of $(Mn,Co)_4C$. S. S. SIDHU, F. P. CAMPOS, AND D. D. ZAUBERIS, *Argonne National Laboratory.*—The compound Mn_2Co_2C is cubic with the unit cell dimension $a_0=3.78$ A. Its magnetic structure, recently reported,[1] is deduced on the basis that the C atom is in the central $\frac{1}{2}\frac{1}{2}\frac{1}{2}$ site and the metal atoms are ordered with the Mn atoms in the 000 and $\frac{1}{2}\frac{1}{2}0$ sites and the Co atoms in the $\frac{1}{2}0\frac{1}{2}$ and $0\frac{1}{2}\frac{1}{2}$ sites. A ternary alloy $Mn_{1.75}Co_{2.25}C$, with a structure similar to Mn_2Co_2C, was prepared by alloying carbon with a binary alloy $Mn_{2.19}Co_{2.81}$. An x-ray diffraction pattern of the binary alloy shows that it is face-centered-cubic with $a_0=3.618$ A, but its neutron pattern gives no Bragg peaks since the Mn atoms scatter thermal neutrons 180° out of phase with those of Co atoms. Therefore, there is no ordering of the metal atoms in this alloy. A neutron diffraction study of $Mn_{1.75}Co_{2.25}C$ then determines uniquely (1) order-disorder of metal atoms, (2)

positions of C atoms, and (3) magnetic moment alignments in its unit cell. These results will be presented and discussed.

[1] Holtzman and Conrad, J. Appl. Phys. **30**, 1035 (1959).

S10. Magnetic Structure of $MnCO_3$.* S. J. PICKART, *U. S. Naval Ordnance Laboratory and Brookhaven National Laboratory.*—A low-temperature powder neutron diffraction study was undertaken in order to investigate the parasitic ferromagnetism[1] observed in rhombohedral manganous carbonate (rhodochrosite) below 31.7°K. The neutron pattern at 4.2°K shows coherent reflections which are traceable to a magnetic ordering, since they follow a Brillouin temperature dependence; these peaks disappeared at about 32°K. The occurrence of these reflections at positions forbidden by the space group can be explained if the alignment of the Mn^{2+} spins is antiferromagnetic, the spin sign alternating around the rhombohedral axis. The observed magnetic intensities are not satisfied if the moments are aligned either parallel or perpendicular to the [111] axis, but a good fit is obtained by taking the spin direction as [100] (though this is by no means a unique solution). The data will be discussed in relation to the "canted spin" model predicted from thermodynamic consideration,[2] as well as to other plausible origins of the parasitic moment.

* Work performed under the auspices of the U. S. Atomic Energy Commission and the National Security Agency.
[1] A. Borovik-Romanov and M. Orlova, Zhur. Eksptl. i Teoret. Fiz. **31**, 579 (1956).
[2] J. Ezyaloshinski, J. Phys. Chem. Solids **4**, 241 (1957).

S11. Antiferromagnetism in $CoBr_2 \cdot 6H_2O$.* H. FORSTAT, M. GARBER, AND R. D. SPENCE, *Michigan State University.*—The magnetic susceptibility, specific heat, and proton resonance of single crystals of $CoBr_2 \cdot 6H_2O$ have been measured in the liquid helium temperature range. The susceptibility measurements show a Néel temperature of 3.2°K with spin alignment direction normal to the monoclinic b axis. If we call the spin direction the a axis, then $\chi_a = 0.60$, $\chi_b = 0.68$, and $\chi_c = 0.18 \times 10^{-3}$ emu/g at 4.2°K. A λ-type anomaly is observed in the specific heat measurements at 3.07°K. The entropy change associated with the magnetic ordering, calculated from the specific heat curve, is 1.42 cal/deg mole. The value of $R\ln(2S+1)$ is 1.38 cal/deg mole where $S = \frac{1}{2}$ for Co^{++}. There is evidence for short range ordering by a 38% contribution to the total magnetic entropy above the Néel point. This is also indicated by a constant susceptibility from 3.2° to 4.2°K. The proton resonance data indicate an antiferromagnetic state below 3.08°K. The resonance pattern shows symmetry about a frequency on the high-frequency side of the free proton resonance and a periodicity of 360° in the angular variation of the individual components.

* Supported by the Office of Ordnance Research, U. S. Army.

S12. Determination of the Magnetic Properties of Solids Using Configuration Interaction. DAVID I. PAUL, *University of California, Los Angeles.*—The theory of strong magnetic effects is investigated from the point of view of orthogonal atomic functions for the case of one dimension. Thus the exchange integral is considered positive and the interaction between the polar and nonpolar states for all possible arrangements of electron spin is included in our formulation of the problem. The resulting secular equations are solved for both large and small interactions between states for the case of only one electron spin oriented in a direction opposite to all other electron spins, and they are solved for small interactions between states for the more general case of any number of electron spins being in a given direction. It is shown how inclusion of the polar states can yield either a ferromagnetic or an antiferromagnetic ground state depending on the differences in absolute magnitude among (1) the exchange integral, (2) the extra Coulomb energy of the polar states, and (3) integrals representing electron-nuclei interactions and thus the splitting of the energy bands.

S13. Magnetic and Electrical Resistivity Properties of Erbium Single Crystals.* R. W. GREEN,† S. LEGVOLD, AND F. H. SPEDDING, *Iowa State University.*—Erbium single crystals have been grown by the Bridgman method. The magnetic properties of these crystals have been determined in fields up to 18 kilo-oersteds with the field applied parallel to and perpendicular to the c axis at 4.2°K and between 20.4°K and 300°K. The c axis was found to be the direction of easy magnetization. A Néel point was observed at 84°K. The ferromagnetic-antiferromagnetic transition temperature inferred from the magnetic data was 19.6°K. The saturation moment $\sigma_{s,0}$ obtained by an extrapolation of the data was 268.7 cgs units/g. Between 1.3°K and 300°K the resistivity was determined with the current parallel to the c axis and also with the current parallel to the a axis. With the current parallel to the c axis a decided increase in resistivity was observed at 20.4°K, the ferromagnetic-antiferromagnetic transition temperature, a large peak occurred at 53.5°K, and a minimum occurred at the Néel point. These features were not observed with the current parallel to the a axis.

* This work was supported by the U. S. Atomic Energy Commission.
† National Science Foundation Science Faculty Fellow.

FRIDAY AFTERNOON AT 2:00

Statler-Hilton Skytop Room

(BENJAMIN LAX presiding)

Semiconductors I, Mostly Theory

SA1. Generalization of Band Theory to Include Self-Energy Corrections.* G. W. PRATT, JR., *Lincoln Laboratory.*—In ordinary energy band theory the Bloch functions are eigenfunctions of a one particle Hamiltonian which itself contains none of the dielectric properties of the medium. Especially in materials like Ge and Si with high dielectric constants one would expect considerable corrections to the energies and effective masses found from band theory. A conduction electron, for example, will polarize the charge distribution of the other electrons of the solid and this induced polarization will react back on the conduction electron leading to changes in its energy and effective mass. A one-particle Schrödinger-like equation will be described whose eigenvalues in certain cases are identical with the energies of the many electron states of a semiconductor or insulator including self-energy corrections. The one-particle Hamiltonian is expressed in terms of the Coulomb interaction as modified by polarization processes. The relation is given between the modified Coulomb interaction and the dielectric function which is the generalization of the classical dielectric constant. It is sug-

gested that the one-particle equation including self-energy effects might be solved in practice by the pseudopotential method of Phillips.

* The work reported in this paper was performed by Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology with the joint support of the U. S. Army, Navy, and Air Force.

SA2. Valley-Orbit Splitting in Germanium from Strain-Induced Shift of Lyman Spectrum. GABRIEL WEINREICH AND HARRY G. WHITE, *Bell Telephone Laboratories.*—An elastic strain applied to a germanium crystal splits all the donor states; but the ground state behaves differently from the p states due to the appreciable valley-orbit interaction,[1] and as a result the absorption lines of the Lyman series (which are in the region of 100 cm^{-1}) also split.[2] The line shifts become nonlinear with strain at sufficiently high strains because of interaction between the singlet and triplet components of the ground state, and from the amount of this nonlinearity the energy separation between the singlet and the triplet can be calculated. In these experiments applied compressions up to about 3×10^{-4} split the lines by up to six times the line width without broadening. Our results for the total singlet-triplet splitting are 3.0 ± 0.3 Mev for phosphorus donors and 3.9 ± 0.6 Mev for arsenic donors.

[1] P. J. Price, Phys. Rev. **104**, 1223 (1956).
[2] Weinreich, Boyle, White, and Rodgers, Phys. Rev. Letters **2**, 96 (1959); **3**, 244 (1959).

SA3. Valley-Orbit Splitting in Germanium from Effect of Strain on the Electron Spin Resonance. D. K. WILSON, *Rutgers University and Bell Telephone Laboratories,* AND G. FEHER, *Bell Telephone Laboratories.*—The ground-state donor wave function in germanium is a singlet. Application of a uniaxial strain admixes the higher lying triplet state which results in a reduction of the hyperfine interaction[1] and in an anisotropic g value.[2] Electron spin resonance experiments were performed at 1.2°K and 9000 Mc/sec on localized electrons in germanium[3] subjected to elastic strains up to 10^{-3}. Assuming a value for the deformation potential of 18 ev, the valley-orbit splitting (i.e., singlet-triplet spacing) for arsenic was found to be 4.2 ± 0.2 milli-ev in agreement with piezoresistance measurements[4] and for phosphorus 2.9 ± 0.2 milli-ev. From the g anisotropy in an arsenic-doped sample under strain we obtained for H perpendicular to the valley axis, $g_\perp=1.92\pm0.05$, and for H parallel to the valley axis, $g_\parallel=0.87\pm0.05$.

[1] P. J. Price, Phys. Rev. **104**, 1223 (1956).
[2] L. M. Roth and B. Lax, Phys. Rev. Letters **3**, 217 (1959).
[3] Feher, Wilson, and Gere, Phys. Rev. Letters **3**, 25 (1959).
[4] H. Fritzsche, Phys. Rev. **115**, 336 (1959).

SA4. Spin-Lattice Interaction for Donor Electrons in Ge and Si.* LAURA M. ROTH, *Lincoln Laboratory.*—The g factors of electrons in Ge and Si differ from two because of spin-orbit interaction, and the results of a calculation indicate strongly that the effect is quite anisotropic, with $g_\parallel$ (i.e., parallel to the axis of the electron's ellipsoids) differing from two by considerably more than $g_\perp$. For donor electrons in either material the ground electronic state is split, due to interactions between the ellipsoids, into a singlet state whose wave function involves a symmetric combination of wave functions from the various ellipsoids, and which is generally lowest, and excited states: a doublet and triplet for Si and a triplet for Ge. The effective g factor or factors depend on which state the system is in, and for the singlet state g is a scalar. One consequence of the anisotropic g tensor is a strong interaction between the spin and shear waves, which modulate the g tensor for the singlet. This interaction can account in order of magnitude for the observed spin-lattice time τ_s in Si for low temperatures including both a one-phonon process and a two-phonon Raman-type process. The temperature and magnetic field dependence of the two processes are predicted to be $\tau_s^{-1}\propto TH^4$ and $\tau_s^{-1}\propto T^7H^2$, respectively.

* The work reported in this paper was performed by Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology with joint support of the U. S. Army, Navy, and Air Force.

SA5. Simplified Theory of Two-Carrier, Space-Charge-Limited Current Flow in Insulators. MURRAY A. LAMPERT, *RCA Laboratories.*—Two-carrier, space-charge-limited currents are analyzed by an extension of the simple but effective method introduced by Rose[1] to treat the one-carrier problem. The key lies in using the lifetime-to-transit-time ratio for free carriers to relate the total injected-carrier density, which is largely electrically neutral, to its small unneutralized portion, the space charge. The latter is, in turn, related to the applied voltage via the geometric capacitance.[1] The analysis has been carried out for those situations where the injected carriers are free and the currents are field driven (diffusion neglected). Results are obtained for both monomolecular and bimolecular recombination. Because of neutralization, far larger currents can result from two-carrier flow than from one-carrier flow at the same voltage. The simplified theory checks very closely the exact result of Parmenter and Ruppel[2] for the bimolecular recombination, field-independent mobility (low field) case.

[1] A. Rose, Phys. Rev. **97**, 1538 (1955); M. A. Lampert, Phys. Rev. **103**, 1648 (1956).
[2] R. H. Paramenter and W. Ruppel, J. Appl. Phys. **30**, 1598 (1959); M. A. Lampert, RCA Rev. (December, 1959).

SA6. Changing Space Charge and Added Carrier Concentrations in Semiconductors. MILTON GREEN, *U. S. Army Signal Research and Development Laboratory.*—No displacement current can result in a circuit unless there is a changing space charge. Space charge in semiconductors results from charge carrier density gradients. [Space charge in a conducting medium is given by $q=(4\pi)^{-1}\,\mathrm{div}D=\mathrm{div}\tau I=I\cdot\mathrm{grad}\tau-\tau\partial q/\partial t$; q, D, I, and τ are, respectively, space charge, electric displacement, current density, and relaxation time ($\tau=\epsilon\rho/4\pi$).] The processes of generation and recombination of charge carriers, *of themselves*, are not space-charge producing mechanisms because the charges involved occur in equal and opposite quantities; but, since these processes constitute sources and sinks, they produce concentration gradients and hence space charge. Associated with transient concentration gradients, there occur time varying components of the hole current density I_p and of the electron current density I_n that are both solenoidal and nonsolenoidal. The sum of the nonsolenoidal components of I_p and I_n just balance out the displacement current $\partial\epsilon E/\partial t$ so that the total current I is everywhere solenoidal, in agreement with Maxwell's equation $\mathrm{Curl}H=4\pi I=4\pi(I_p+I_n)+\partial\epsilon E/\partial t$—confirmed also by the results of W. Van Roosbroeck.[1]

[1] W. Van Roosbroeck, Bell System Tech. J. **29**, 568 (1950).

SA7. Microwave Heating of Electrons in Semiconductors. B. V. PARANJAPE, *Louisiana State University* (sponsored by J. S. Levinger).—Morgan and Seeger have measured mobilities of hot electrons using high microwave fields. In the present paper we calculate electron temperature as a function of the applied microwave field and its frequency. The calculation is based on a simplified model developed by Fröhlich where he assumes that under the influence of a strong external electric field, electrons are at a temperature T much higher than that of the lattice. Neglecting interaction of electrons with optical modes, it is shown that at high frequencies ($\omega>\omega_c$) of the microwave field, electronic temperature which must oscillate with twice the applied frequency, always stays a finite distance above lattice temperature T_0. The critical frequency ω_c is given by $2(kT_0/m^*s^2)\omega_c\tau\sim1$. Here τ is the mean collision time at the highest electronic temperature, and s is the speed

of sound in the medium. By using these results one can calculate properties associated with electrons heated up by microwaves.

SA8. Scattering of Hot Carriers in Germanium. E. M. CONWELL, *Sylvania Electric Products Inc.*—The theory of scattering by acoustical lattice modes is extended to cover carriers with energy many times the thermal value at lattice temperatures of 20°K and above. In the limit where the carriers interact mainly with lattice oscillators having only zero point energy, it is found that the relaxation time for acoustical mode scattering is proportional to the inverse square of the speed rather than to the inverse first power as it is for thermal carriers. Lattice mobility has been calculated as a function of average carrier energy for various values of the ratio of coupling constants for acoustical and optical modes and various effective masses for lattice temperatures of 300, 78, and 20°K. The effect of dropping the assumption of equipartition of energy among the acoustical lattice oscillators is to increase the scattering effect of the acoustical modes. This increase is greater the lower the lattice temperature, the higher the carrier temperature, and the higher the mass of the carriers. It will also be shown that the effect of impurity scattering in increasing hot-carrier mobility will generally be smaller than has been expected.

SA9. Nonequilibrium Cyclotron Resonance of Negative Effective Mass Carriers. ROSCOE C. WILLIAMS AND FRANK HERMAN, *RCA Laboratories.*—The classical Boltzmann theory of cyclotron resonance for warped surfaces has been extended to cover the case of a nonequilibrium carrier distribution arising from generation and recombination processes. As a specific application, we have examined the cyclotron resonance of optically-excited holes in Ge, with a circularly polarized rf electric field, and a (100)-directed magnetic field. The power absorption (as a function of magnetic field) can be obtained in closed form if (a) the actual energy contours are approximated by circularly averaged warped surfaces of revolution, and (b) the generation, recombination, and scattering terms are represented by suitable analytic forms which account for energy dependence and anisotropy in momentum space phenomenologically. If the negative mass population is enhanced at the expense of the positive mass population (in the heavy hole band) to a degree of the order of the energy band warping, the power absorption is found to be negative for magnetic field values for which the negative mass holes are resonant. Such a region of negative absorption is indeed observed.[1] The type of nonequilibrium heavy hole distribution required to produce negative absorption is readily obtained by making physically plausible assumptions regarding the generation, recombination, and scattering terms.

[1] Dousmanis, Duncan, Thomas, and Williams, Phys. Rev. Letters **1**, 404 (1958).

SA10. Theory of Solubility of Interstitial Impurities in Semiconductors. KURT WEISER, *I.B.M. Research Laboratory, Poughkeepsie.*—For a given concentration of the impurity in the gas phase, the solubility is largely determined by the energy needed to transfer the impurity to an interstitial site in the host crystal. For neutral and ionized impurities, respectively, we assume:

$$\Delta E_{\text{neutral}} \approx \frac{\alpha_i \alpha_h}{r^6} \frac{(\text{I.P.})(h\nu_{\max})}{(\text{I.P.})+(h\nu_{\max})} + \frac{(\lambda_i+\lambda_h)^9}{r^9}$$

$$\Delta E_{\text{ion}} \approx \text{I.P.} - \text{W.F.} - U_{\text{pol}} + \frac{(\lambda_i+\lambda_h)^9}{r^9}$$

where the α's stand for polarizability, I.P. for ionization potential, W.F. for work function, $h\nu_{\max}$ for a characteristic absorption energy of the host crystal. The λ's are overlap parameters, and r is the distance from the impurity to the nearest host atom. U_{pol} is the polarization energy, which was calculated by the method of Mott and Littleton.[1] The theory can predict whether an impurity will be neutral or ionized, and predicts relative solubilities. The case of hydrogen and copper will be discussed.

[1] N. F. Mott and M. J. Littleton, Trans. Faraday Soc. **34**, 485 (1938).

Invited Paper

SA11. Solid-State Ionization Chamber. S. S. FRIEDLAND, *Hughes Research Laboratory.* (30 min.)

FRIDAY EVENING AT 7:00

New Yorker Grand Ballroom

(G. E. UHLENBECK AND F. W. SEARS presiding)

Banquet of The American Physical Society and the AAPT

After-dinner speaker: G. B. KISTIAKOWSKY, *Special Assistant to the President for Science and Technology*

SATURDAY MORNING AT 9:30

Statler-Hilton Skytop Room

(L. M. ROTH presiding)

Semiconductors II

T1. Electrical and Optical Effects of Oxygen in Germanium. W. KAISER, H. J. HROSTOWSKI, AND C. D. THURMOND, *Bell Telephone Laboratories.*—Oxygen dissolved in germanium can be detected by an infrared absorption band.[1] Germanium single crystals were doped with oxygen via the ambient and the intensity of the absorption band at 11.69 μ was quantita-

tively correlated with the oxygen content determined by vacuum fusion gas analysis.* During heat treatment at several hundred degrees centigrade donor states appear[2] quite rapidly (minutes) and the amount of dissolved oxygen decreases. At 470°C the ratio of loss of dissolved oxygen atoms/number of donors formed, is approximately four indicating that the donors result from aggregates of oxygen atoms similar to those found in silicon.[3] A series of small absorption bands at 7.95 μ, 10.81 μ, 12.3 μ, and 12.8 μ appears during the heat treatment of germanium (similar bands occur at 9.5 μ and 9.75 μ in silicon). They are attributed to vibrations of various germanium-oxygen (silicon-oxygen) aggregates. The band at 12.8 μ is proportional to the donor concentration (formed at 470°C) and it is tentatively assigned to a GeO_4 vibration. Precipitation of oxygen is observed after long annealing (65 hr) at high temperatures (e.g., 650°C).

[1] Kaiser, Keck, and Lange, Phys. Rev. **101**, 1264 (1956); Bloem, Haas, and Penning, J. Phys. Chem. Solids (to be published).
[2] G. Elliot, Nature **180**, 1350 (1957); W. W. Tyler, Bull. Am. Phys. Soc. Ser. II, **4**, 145 (1959); C. S. Fuller (to be published).
[3] Kaiser, Frisch, and Reiss, Phys. Rev. **112**, 1546 (1958).
* We are indebted to W. G. Guldner and A. L. Beach for performing the vacuum fusion gas analyses.

T2. Energy Levels in Gold-Doped p-Type Germanium.* P. P. DEBYE, C. A. KLEIN, AND G. RUPPRECHT, *Raytheon Company.*—Hall- and pulsed-field effect studies have been made as a function of temperature on p-type Ge samples with Au concentrations ranging from 10^{14} to almost 10^{16} cm^{-3}. The aim of this program was to arrive at a better description of the donor level at $E_v+0.041$ ev as well as the acceptor level at about $E_c+0.14$ ev, and by the same token to improve the evaluation of both the gold and the counter-doping's concentrations. A correct appreciation of the statistical factors g_D and g_A associated with the two levels appears to be the critical factor. Hall-effect experiments were found susceptible of leading to this information, if care is taken in estimating the Hall coefficient factor μ_H/μ and applying adequate statistics to the multilevel situation in Au-doped Ge. Presently available results point towards $g_D \sim \frac{1}{4}$,indicating that the valence electron of substitutional Au in the Ge lattice has indeed an S-state character, as might be expected on the basis of the tetrahedral bonding model. Besides yielding accurate majority carrier capture cross sections, the pulsed field effect approach provides straightforward indications on the level's position and density. These indications will be confronted with the results of the Hall data analysis.

* Work supported in part by the Bureau of Aeronatuics, U. S. Navy.

T3. Internal Impurity Levels in p-Type Silicon.* SOLOMON ZWERDLING, KENNETH J. BUTTON, AND BENJAMIN LAX, *Lincoln Laboratory.*—New transitions to discrete impurity levels within the valence bands, associated with the split-off $p_{\frac{1}{2}}$ band have been found. Infrared measurement of the spin-orbit splitting of this band gave a value $\Delta=0.044$ ev and a hole mass $m^*=0.21m_0$ for the $p_{\frac{1}{2}}$ band at $k=0$. The observations were made for both boron and aluminum impurities of $\sim 5\times10^{15}$/cm^3. The levels fit the Rydberg formula $\varepsilon_n = 13.6m^*/n^2\kappa^2m_0$, yielding the effective mass and the series limit ε_I^* for hole excitation from the gap ground state to the band maximum. The spin-orbit splitting is therefore $\Delta=\varepsilon_I^* - \varepsilon_I$, where the ε_I values are known.[1] Linear Zeeman splitting was also observed from the $2p'$, $3p'$, and $4p'$ levels. The effective mass calculated from the $\mathbf{E}\perp\mathbf{B}$ Zeeman spectrum for the $2p'$ level was in good agreement with the Rydberg effective mass. The unexpected splitting for $\mathbf{E}\parallel\mathbf{B}$ for a simple spherical band reflects the complexity of the ground state. Transitions to bound Landau states above ε_I^* were also found. The $p_{\frac{1}{2}}$ band mass differs from the value deduced from cyclotron resonance [2] $m^*=0.25m_0$.

* The work reported in this paper was performed by Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology with the joint support of the U. S. Army, Navy, and Air Force.
[1] H. J. Hrostowski and R. H. Kaiser, J. Phys. Chem. Solids **4**, 148 (1958).
[2] Dresselhaus, Kip, and Kittel, Phys. Rev. **98**, 368 (1955); Dexter, Zeiger, and Lax, Phys. Rev. **104**, 637 (1956).

T4. Optical Absorption in Tellurium. K. C. NOMURA AND J. S. BLAKEMORE, *Honeywell Research Center.*—Transmission techniques have been used in single tellurium crystals at 300°K and 110°K to measure the optical absorption coefficient as a function of polarization from 1000 cm^{-1} to 0.2 cm^{-1}. Previous theories have suggested that the conduction and valence band extrema occur at the same point in the Brillouin zone. Our results cast doubt on this, since the results can be interpreted most readily in terms of indirect (phonon-aided) transitions for both polarizations. The absorption edge shifts by -2×10^{-5} ev/°K for radiation polarized parallel to the c axis and at a rate of -3.5×10^{-5} ev/°C for the perpendicular polarization.

T5. Recombination through Dislocations in Tellurium. J. S. BLAKEMORE AND K. C. NOMURA, *Honeywell Research Center.*—It has been established that dislocations have a marked effect on lifetime in tellurium single crystals, both at room temperature and in the liquid air range. Tellurium as grown may have as few as $N_D\sim10^3$ dislocations/cm^2, but since the material is very soft, slight flexural stress can easily introduce as many as 10^6 cm^{-2}. For samples whose lifetime is dominated by the presence of dislocations, the room temperature recombination rate (in sec^{-1}) is about equal to N_D (in cm^{-2}). It also appears that dislocations contribute to the minority electron trapping seen at low temperatures in tellurium.[1] Dislocation densities can readily be measured from counts of etch pits on the cleavage $10\bar{1}0$ planes. A fast acting etch such as CP4 yields pits of poorly defined shape; but when Te is slowly attacked with sulfuric acid, the pits have well-defined planar surfaces corresponding to $1\bar{1}00$, $10\bar{1}3$, $01\bar{1}1$, and $0\bar{1}1\bar{1}$ faces.

[1] Blakemore, Heaps, Nomura, and Beardsley, Phys. Rev. (to be published).

T6. Calculation of Mobility in n-Type GaAs. EMIL ARNOLD, *Sylvania Research Laboratories.*—Theoretical calculation was made of carrier mobility using the Fermi distribution function and incorporating lattice and impurity scattering. This type of calculation is necessary for the determination of electron mobility at room temperature in typical GaAs samples having a carrier concentration of about 10^{17} cm^{-3} or larger because the small effective mass causes the Fermi level to be near the edge of the conduction band. The relaxation time was obtained by adding the reciprocals of the relaxation times for acoustical phonon scattering and for Brooks-Herring impurity scattering. It was assumed that the total ionized impurity concentration was equal to the free carrier concentration. Spherical constant energy surfaces were also assumed. The resulting scattering integrals were evaluated numerically. Three adjustable parameters were used: the reduced Fermi level η, the effective mass m^*, and the mean free path for acoustical mode scattering l. The ratio r of Hall to drift mobility and the relationship between μ/μ_L and μ_L/μ_I valid for different degrees of degeneracy were determined. In the nondegenerate limit the mobility is somewhat larger than that given by Conwell because, in the present calculation, the approximation of replacing the logarithmic term in the expression for the impurity relaxation time by a constant has not been made.

T7. Evidence for a Mobility Killer in GaAs, InAs, and InP.* L. R. WEISBERG AND J. BLANC, *RCA Laboratories.*—Carrier

mobilities in semiconductors have been interpreted mainly in terms of lattice scattering and ionized impurity scattering. On this model, *n*-type GaAs, InAs, and InP were previously believed to be almost always compensated by 75% or more, since their room-temperature mobility values were far below those expected for given electron concentrations. However, considerable evidence has accumulated against such an interpretation: (1) Over 99% of all crystals prepared turn out *n*-type; (2) at given electron concentrations, curves of mobility *versus* temperature for different samples are observed to cross; (3) at 300°K there is no correlation between measured mobilities and carrier concentrations, while at 78°K a correlation exists; (4) erratic mobility variations observed along an ingot are percentagewise greater at 300°K than at 78°K; (5) purification of the elements cause changes in the mobility at 78°K with no corresponding change at 300°K and vice versa. All of these phenomena can be accounted for by assuming that the samples are actually uncompensated, but that a mobility "killer" is present having little effect on the electron concentrations. Analysis of the available data indicates that the mobility of this new scatterer varies with temperature roughly as $T^{-\frac{1}{2}}$.

* Sponsored by the Electronics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command.

T8. Effects of High Hydrostatic Pressure on the Electrical Properties of *n*-Type GaSb. A. SAGAR, M. POLLAK, AND R. W. KEYES, *Westinghouse Research Laboratory.*—We have measured the electrical conductivity, Hall constant, and piezoresistance tensor Π of several samples of *n*-type GaSb (2 to 80×10^{17} donors/cm^3) as functions of hydrostatic pressure up to 12 000 kg/cm^2 at 300°K. The results are roughly as follows, with details depending considerably on the inpurity content. The conductivity decreases rapidly at first, and at high pressures levels off at about one-third of the initial conductivity. The Hall constant passes through a flat maximum and then decreases to one-half or less of its initial value at high pressures: $(\Pi_{11}+2\Pi_{12})$ decreases rapidly initially and approaches zero at high pressure. Π_{44} is about 80 at atmospheric pressure, increases with increasing pressure, and approaches a value of about 200 at high pressures (in units 10^{-12} cm^2/dyne). $\Pi_{11}-\Pi_{12}$ is small throughout the entire pressure range. These results can be understood in terms of the model of the band structure recently proposed by Sagar.[1] According to this model there are electrons in both the (000) and (111) conduction band extrema at atmospheric pressure. However, the (000) energy increases much more rapidly with increasing pressure than the (111) energy.

[1] A. Sagar, thesis, University of Pittsburgh (1959); Phys. Rev. (to be published).

T9. Electrical Properties of *n*-Type Cadmium Sulfide. W. W. PIPER AND R. E. HALSTED, *General Electric Research Laboratory.*—The conductivity and Hall coefficient of single-crystal samples of hexagonal CdS:Ga have been measured between 20°K and 350°K. These crystals were grown from the vapor phase. Initial measurements have been performed on bars, $2\times2\times10$ mm, cut with the long dimension perpendicular to the *c* axis. The Hall voltage was measured both parallel to and perpendicular to the *c* axis. Gallium was incorporated in the crystals as they were grown. A gallium concentration greater than 5×10^{16} cm^{-3} yielded samples with low resistivity due to the presence of uncompensated donors. Above a concentration of Ga of 10^{18} cm^{-3} the Hall coefficient R_H was almost independent of temperature in agreement with earlier work by Kröger *et al.*[1] At lower concentrations R_H increased exponentially with increasing reciprocal temperature. At low temperatures, behavior consistent with competition from impurity band conduction was encountered. The Hall coefficient has been observed to be anisotropic and was larger when the Hall voltage was measured parallel to the *c* axis. Comparison will be made with recent measurements by Masumi[2] and by Miyazawa *et al.*[3]

[1] Kroger, Vink, and Volger, Philips Research Repts. **10**, 39 (1955).
[2] T. Masumi, J. Phys. Soc. Japan **14**, 47 (1959).
[3] Miyazawa, Maeda, and Tomashima, J. Phys. Soc. Japan **14**, 41 (1959).

T10. Non-Ohmic Electrical Conductivity of CdS at Low Temperatures. H. SHENKER, *U. S. Naval Research Laboratory.*—The CdS samples investigated had no intentionally added impurities and had room-temperature conductivities in the range 0.1 to 10 ohm^{-1} cm^{-1}. At liquid helium temperatures the dark conductivity of these crystals was found to increase rapidly with increasing electric field. A typical increase is three orders of magnitude for an increase of electric field from zero to 400 volts/cm. The conductivity appears to be mainly of the impurity band type since the Hall voltage was too small to be measured and the thermal activation energy for the conductivity is in the milli-electron-volt range. The dependence of the conductivity upon electric field varies from sample to sample, but can generally be approximated by a sum of two or three exponentials in the first power of the electric field. Several samples were found to exhibit a reversible breakdown effect somewhat similar to that in germanium. This breakdown occurs in the range 350 to 450 volts/cm. The breakdown field has a small dependence upon temperature and also upon applied magnetic field. The crystals also exhibit infrared photoconductivity with a cut off at 32 microns.

T11. Fluctuations, Neutral Transport, and the Photoconductive Process in CdS.* ROBERT J. ROBINSON AND JAMES J. BROPHY, *Armour Research Foundation.*—Evidence of long-range neutral energy transport in CdS using photodiffusion techniques in conjunction with photoconductive measurements has frequently been reported since the original mention in 1956, where neutral energy transport refers to the migration of electrically neutral energy at velocities of propagation much smaller than that of light which rules our direct scattering by multiple reflections. New evidence for neutral transport obtained from electrical noise measurements is herein reported. In addition, evidence is presented from the magnitude of the noise intensity, response times and conduction band lifetimes which suggest that the dynamics of the photoconductive process are different for photodiffusion compared to uniform illumination induced photoconductivity. The current noise spectra of a lightly CuCl doped single crystal of CdS which showed long-range photodiffusion was studied under both uniform and masked (photodiffusion) illumination using 5200 A radiation. In the photodiffusion curves a new generation or relaxation (GR) process is evident which is present at all radiation levels, and which does not appear with uniform illumination. This additional GR process has a 500 microsecond time constant.

* Supported by the Office of Naval Research.

T12. Frequency Factor of Shallow Traps in CdS.* JAMES J. BROPHY AND ROBERT J. ROBINSON, *Armour Research Foundation.*—Current noise and photoconductivity measurements taken under uniform 5200 A illumination on lightly CuCl-doped CdS single crystals are used to determine the energy distribution and frequency factor of shallow traps in the range 0.3 to 0.5 ev below the conduction band. The current noise observed is interpreted in terms of multiple retrapping in these levels and results in a new way of determining the trap escape probability. Both discrete states and a continuous distribution in energy are found in different crystals. The distributed states all have the same frequency factor, which may imply the traps are structurally similar. It is possible to account semiquantitatively for the $1/f$ noise spectrum observed in some crystals at high frequencies using the near exponential trap distributions found from photoconductivity measurements and the constant frequency factor derived from low-frequency noise measurements.

* Supported by the Office of Naval Research.

SATURDAY MORNING AT 9:30

Statler-Hilton Grand Ballroom

(G. E. UHLENBECK presiding)

Invited Papers

TA1. What Can Be Proved and What Has Been Proved about Dispersion Relations, and On What Basis? K. SYMANZIK, *Institute for Advanced Study.* (30 min.)

TA2. Speculations about Possible Experiments with High-Energy Neutrinos. T. D. LEE, *Columbia University.* (30 min.)

Addresses in Memory of Wolfgang Pauli

TA3. Pauli and the Theory of Spectra. S. A. GOUDSMIT, *Brookhaven National Laboratory.* (30 min.)

TA4. Pauli and the Development of Modern Theoretical Physics. V. F. WEISSKOPF, *M. I. T.* (30 min.)

SATURDAY MORNING AT 9:15

New Yorker, Boston Room

(H. A. BETHE presiding)

Theoretical Physics VI: Quantum Mechanics

U1. A Generalized Exclusion Principle. DAVE PANDRES, JR., *Ohio Oil Company Research Center.*—Admissibility conditions for wave functions describing single- and many-body systems have been derived, without restrictions concerning the nature of the Hamiltonian, simply from the fact that momenta are observable. If ψ and ϕ are functions of general ξ coordinates related to Cartesian coordinates by a Jacobian $J(x/\xi)$, and all of space corresponds to the region $a_k \leqslant \xi_k \leqslant A_k$, the conditions state, essentially, that $\psi^*\phi J(x/\xi)$ must vanish on the manifolds $\xi_k = a_k, A_k$ and be continuous across any interior manifold ξ_k = constant. One consequence of the conditions (applicable either for localizable systems in the Schrödinger representation, or nonlocalizable systems in the Foldy-Wouthuysen[1] representation) is a generalized exclusion principle which states that as the coordinates of two particles approach each other, the wave function must approach zero. This principle reduces to the antisymmetry principle if the particles are identical. Since the content of the admissibility conditions is not exhausted by the generalized exclusion principle (e.g., in spherical coordinates they yield Dirac's[2] requirement that $r\psi$ vanish for $r=0$), it is suggested that other laws of symmetry may be derivable from them and their field-theoretic equivalents.

[1] L. L. Foldy and S. A. Wouthuysen, Phys. Rev. **78**, 29, (1950).
[2] P. A. M. Dirac, *Quantum Mechanics* (Oxford University Press, London, 1958), fourth edition, p. 156.

U2. Elementary Picture of Nonexponential Decay.* ROLF G. WINTER, *The Pennsylvania State University.*—Several studies of models of unstable states have demonstrated large time deviations from exponential decay. Khalfin[1] proved that any state whose energy spectrum contains a lowest energy must, eventually, decay more slowly than exponentially. The time at which deviations become important is model dependent, but is generally a few times the logarithm of the energy of decay divided by the width of the state. To gain some understanding of these results, the decay of a wave packet through a delta function barrier has been studied, both for nonrelativistic particles and for relativistic mass zero particles. The time development of the wave functions will be presented. The results support the following simple picture: High-energy components of the initial packet leave faster than low-energy components, so that the mean energy of the remaining system and, therefore, the rate of decay decrease, As time approaches infinity, the mean energy approaches the lowest energy present initially, and the rate of decay, per remaining system, approaches zero.

* Supported in part by the Office of Ordnance Research, U. S. Army.
[1] L. A. Khalfin, Soviet Phys.—JETP **6**, 1053 (1958).

U3. Proposed Elementary Particle Model. J. W. HAFFNER, *Radiation Counter Laboratories, Inc.*—With the development of the 2-component neutrino theory, the analogy between the neutrino and the electromagnetic fields can be further investigated. In particular, this suggests a model for elementary particles. All particles of a given charge are postulated to be different quantum states of one fundamental particle. Transitions between these different quantum states take place by the emission of neutrinos or anti-neutrinos. Positively charged particles are accounted for an an extension of Dirac's theory of negative energy states. All neutral particles are considered to be combinations of charged particles. The applications of this theory to the characteristics of nuclear reactions and the properties of elementary particles will be considered.

U4. On the Origin of Super Selection Rules. SAUL T. EPSTEIN, *University of Nebraska.*—Assertion: all the suggested super selection rules[1] can be derived from the assumption[2] that *every realizable pure state at one time involved definite numbers of each kind of particle.*[3] Proof: an observable will be subject to a super selection rule if every pure state involving definite numbers of each kind of particle is an eigenstate of the observable, and if the observable is a constant of the motion, since then it follows from our assumption that one cannot prepare a coherent superposition of eigenstates belonging to different eigenvalues of the observable. It is now trivial to verify that the only observables satisfying these conditions are those already suggested.

[1] Wick, Wightman, and Wigner, Phys. Rev. **88**, 101 (1950); Matthews, Nuovo cimento **6**, 642 (1957).
[2] From an experimental point of view this assumption seems very reasonable. To attempt to give it a deeper theoretical basis would presumably involve a considerable discussion of the measuring process.
[3] By "particle" we mean any localizable, recognizable entity, stable or unstable, elementary or compound.

U5. Approximate Calculation of Atomic Energy Levels.* PETER WALSH, *Westinghouse Lamp Division*, AND SIDNEY BOROWITZ, *New York University*.—We have calculated the ground state and some excited state energies for all atoms from $Z=2$ to $Z=30$ approximately, according to the following scheme. The Hamiltonian of the system is written in terms of the electronic coordinates $\mathbf{r}_i$ and the interelectron coordinates r_{ij}. A term of the form $b_{ij}\partial^2/\partial r_{ij}^2$ is added and subtracted from the Hamiltonian. The energies are calculated from the The unperturbed Hamiltonian which includes the term just added and all terms which depend only on the r_i and r_{ij}. unperturbed Hamiltonian is separable and the energies can be calculated from it once the b_{ij} and the exponential growth of the confluent hypergeometric function in r_{ij} at infinity is determined. To fix the latter we assume that the nth electron is in a Coulomb field for $Z-(n-1)$ electrons at infinity. The constants b_{ij} are determined so as to minimize the effects of the perturbation assuming that the form of the unperturbed wave function is correct. The maximum error of the energies so calculated is approximately 4% for the atoms we have investigated.

* Supported in part by contract with the Geophysics Research Division of the Air Force Cambridge Research Center and the Office of Ordnance Research of the U. S. Army.

U6. Upper Bounds on the Electron-Hydrogen Atom Scattering Lengths.* LEONARD ROSENBERG, LARRY SPRUCH, AND THOMAS F. O'MALLEY, *New York University*.—Recently developed variational techniques for determining upper bounds on scattering lengths are applied to singlet and triplet scattering of zero-energy electrons by hydrogen atoms. The only assumption involved is that there is no bound triplet state and one (and only one) bound singlet state, in agreement with experimental and theoretical indications. It follows that the Kohn variational principle provides an upper bound on the triplet scattering length A_T, independent of the accuracy of the trial function, and converges to A_T from above as the trial function is improved. A similar statement can be made for the singlet scattering length A_S, with the restriction that the trial function contain as one of the terms a trial H^- function which is sufficiently accurate to give binding. The results are somewhat lower, and therefore better, than those previously obtained by variational methods. We find $A_T \leq 1.91a_0$ and $A_S \leq 6.23a_0$, where a_0 is the Bohr radius.

* Sponsored by both the Geophysics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command, and the Office of Ordnance Research, U. S. Army.

U7. On a Quasi-Empirical Method of Estimating the Accuracy of the Ground-State Energy of the Helium Atom.* H. M. SCHWARTZ, *University of Arkansas*.—The bounds of the ground state non-relativistic solution for the energy of the helium atom are at present known only to within 0.0008%.[1] This is short by a factor of about 30 of the accuracy which is needed if one is to have a reliable check on at least the lower order radiative corrections that have been calculated.[2] In view of the large number of parameters in the approximating wave functions already employed,[1] it may not be practical to push the accuracy of the energy limits by a direct method, so that it becomes desirable to find these limits at least by an argument admitting of a high degree of plausibility. Such an argument will be presented. It involves the use of $\langle H^2 \rangle$, which in the present case gives either a lower or an upper bound. This approach has already been proposed,[3] but at a time when our state of knowledge both of the experimental value of the ionization potential and of the approximating state functions was not such as to make this approach useful. It is intended to show that this is no longer the case.

* Supported in part by the U. S. Atomic Energy Commission.
[1] T. Kinoshita, Phys. Rev. **115**, 366 (1959).
[2] J. Sucher, Phys. Rev. **109**, 1010 (1958) and references therein.
[3] W. Romberg, Physik. Z. Sowjetunion **8**, 516 (1935).

U8. New Mechanism for Probability in Quantum Mechanics. GEORGE YEVICK, *Stevens Institute of Technology*, AND JEROME K. PERCUS, *New York University*.—We start our analysis of quantum theory by considering a positive probability density in phase space. The fundamental concept is embodied in the notion of a jump in phase space denoted as a "jolt" to distinguish it from the "jump" in momentum occurring in classical physics. We find that the statistical distribution of the jolts exhibits a tremendous correlation dependence between Δp and Δq giving rise to the uncertainty principle, whereas the dispersion for Δp and Δq separately is negligible. The statistical distribution of the jolts, which we term the "inner probability" in contra-distinction to the probability density in phase space that is actually measured ("outer probability"), forms the essential basis for the understanding of quantum mechanics; e.g., in the Gamow penetration, the potential barrier is no longer smooth; rather, the particle suffers violent random jolts due to the inner probability which gives rise to its capability for penetrating the barrier. Another example is the spread of a free particle wave packet and the ability to find a particle very far from an initially localized position; here the particle suffers violent jolts in phase space in contrast to classical physics.

U9. Effective Mass in Quantum-Mechanical Phase Space. JEROME K. PERCUS, *New York University*, AND GEORGE YEVICK, *Stevens Institute of Technology*.—The quantum-mechanical transport equation in phase space (following Bopp's approach[1]) for a free particle exhibits novel features in that the Green's function cannot be found because of the uncertainty principle. We have studied in detail a modified transport equation which for large time intervals gives rise to the usual quantum probability distribution. In so doing we have uncovered the fact that the essential key to the problem of finding a positive inner probability lies in the notion of a positive "effective mass" in phase space. We can construct a transport equation which is guaranteed to give us positive inner probability densities, even for very short time intervals. To do this, we have generated a procedure based upon the Feynman-Dirac path integral formulation of quantum mechanics, which permits us to determine the general Liouville equation for outer probability in phase space in a straight forward manner. Our equation exhibits new characteristics for exceedingly short time intervals, but rapidly goes over into the usual quantum mechanics.

[1] F. Bopp, Ann. inst. Henri Poincarè **15**, 81 (1956).

U10. Configurational Description of the Photon.* R. ACHARYA, K. BARDAKCI, AND E. C. G. SUDARSHAN, *University of Rochester* (introduced by J. J. de Swart).—The method of Wigner and Newton[1] for constructing the localized states of an "elementary system" is seen to be inadequate for the description of the localized states of particles with zero mass and spin one or greater, in particular, for the case of the photon. An attempt is made to clarify the concept of "position" in connection with the photon. The configurational description of the photon (and similar systems) in terms of generalized coordinates is introduced; a possible set of generalized coordinates are the "distance traversed" (longitudinal position) and the direction of motion. The corresponding eigenfunctions, which are the localized states of the photon, are explicitly constructed. It is concluded that a satisfactory description of "position" of a relativistic "elementary system" in a sense generalizing that of Wigner and Newton is always possible in terms of generalized coordinates which have canonically conjugate momenta, provided one removes the restriction to a description solely in terms of Cartesian coordinates.

* Supported in part by the U. S. Atomic Energy Commission.
[1] T. D. Newton and E. P. Wigner, Revs. Modern Phys. **21**, 400 (1949).

U11. Uniqueness of the Orbital Angular Momentum Operators. J. S. LOMONT, *IBM Research Center, Yorktown Heights,* AND H. E. MOSES,* *New York University.*—The uniqueness of the linear momentum operators has been proved by Dirac.[1] We have given an analogous proof for the uniqueness of the orbital angular momentum operators. The crucial point of our proof is to show that every solution of the system of partial differential equations $\mathbf{L}\times\mathbf{f}=i\mathbf{f}$ has the form $\mathbf{f}=\mathbf{L}\phi$ where $\mathbf{L}=-i\mathbf{x}\times\nabla$. This is shown by expanding $\mathbf{f}(\mathbf{x})$ in a series of spherical harmonics, and thereby transforming the analytic problem into an algebraic problem. As a corollary we have obtained a Helmholtz theorem for the orbital angular momentum operator.

* The work of H. E. M. was done under Contract with Office of Ordnance Research, U. S. Army.
[1] P. A. M. Dirac, *Principles of Quantum Mechanics* (Oxford University Press, London, 1958), fourth edition, p. 89.

U12. On the Structure of Perturbation-Theoretic Integrals.* CHARLES M. SOMMERFIELD, *Harvard University.*—A method of carrying out the quadratures involved in perturbation integrals of field theory which contain an integration over a single virtual four-momentum is developed. The inherent mathematical symmetries of the expressions are maintained explicitly at each stage. It is shown that an integral characteristic of a process involving n incoming or outgoing particles may be expressed as the sum of n terms, each of which is in the form of a one-dimensional integration of an expression involving only n-1 incoming or outgoing particles. By continuing in this manner we obtain an integral representation for the original expression which is in the form of a sum of $n!$ n-fold iterated integrals. This representation has the advantage that the singularities are explicitly evident in regard to both location and type.

* Supported in part by the U. S. Air Force Office of Scientific Research.

U13. On the Significance of Potentials in Quantum Theory. W. H. FURRY AND N. F. RAMSEY, *Harvard University.*—The effects of the scalar and vector potentials in quantum mechanics, which were pointed out recently by Aharonov and Bohm, are here discussed from the point of view of the consistency of the quantum-mechanical description of interference experiments. A well-known requirement for this consistency is that if any measuring device is introduced that can be used to determine which path the particle has taken, it must have the effect of eliminating the interference phenomenon. Two conceptual experiments are discussed, corresponding to the two phase effects noted by Aharonov and Bohm. In each case it is found that the phase effect is of just the magnitude required to destroy the interference pattern when the circumstances are such that no pattern should be observed.

U14. Scattering Length and Effective Range Theory for a System of Three Coupled Two-Particle Channels.* MARC ROSS AND GORDON L. SHAW, *Indiana University.*—Previously[1] we investigated the properties of a system of coupled 2-*particle* channels near the threshold of one (the "new" channel). A number of exact and approximate relationships were derived for the following: the complex scattering length ($a\equiv A-iB$) and effective range describing the new channel and the phase shifts in the old channels. For example, we found by introducing "uncoupled" phase shifts in the old channels (i.e., the phase shifts that would exist if we switched off the coupling to the new channel) that, in the 2 channel problem, $c=(B+c_0(L-A))/((L-A)-c_0B)$, where c is the diagonal K matrix element in the old channel at the threshold of the new channel, c_0 is the "uncoupled" c, and L is related to the range of the interaction in the new channel. The relationships in I were derived in general for a system of 2 coupled channels. We, now, extend the theory in I to the general 3 channel problem, which is of interest, for example, in application to the $\bar{K}-N$ problem.[2]

* Supported in part by The National Science Foundation.
[1] M. Ross and G. Shaw, Ann. Phys. (N. Y.) (to be published), referred to as I.
[2] M. Ross and G. Shaw, Phys. Rev. (to be published).

SATURDAY MORNING AT 9:30

Statler-Hilton, Penn Top South

(L. J. LIDOFSKY presiding)

Nuclear Reactions and Energy Levels III

UA1. Branching Ratio of the Second 2+ Level of Zn^{64} and Zn^{66}.* R. RIKMENSPOEL AND D. M. VAN PATTER, *Bartol Research Foundation.*—Isotopically enriched thin targets on Formvar backings of Zn^{64} and Zn^{66} were bombarded with protons with $Ep\leq 5$ Mev. The beam stopper and defining slits were at about 8 in. from the target for reducing background due to bremsstrahlung and impurities on slits and beam stopper. Gamma rays from the decay of the first and second 2+ levels of both isotopes were observed at angles relative to the incoming beam varying from 30° to 150°. For the branching ratio (cross-over/cascade) for the 1.80 Mev, 2+ level in Zn^{64} a preliminary value of 0.41 was found. This value is in essential agreement with the value of 0.34 measured by Jacobi[1] from radioactive decay. A preliminary value of 0.06 for the upper limit for the branching ratio of the 1.87 Mev, 2+ level of Zn^{66} was found. These values indicate a difference for $B(E2;2'\rightarrow 2)/B(E2;2'\rightarrow 0)$ between these two nuclei of at least a factor of 7 (assuming all transitions to be of pure $E2$ character), for which there seems no theoretical explanation.

* Supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
[1] T. Jacobi, as quoted by D. J. Horen, Phys. Rev. **113**, 572 (1959).

UA2. Nuclear Electric Monopole Transition in Ge^{72} and Zr^{90}.* M. NESSIN AND T. H. KRUSE, *Columbia University.*—The excitation function for population of the O^+ first excited states of Ge^{72} and Zr^{90}, has been determined for $E_p=2.3$ to 6.3 Mev. Thin evaporated metal targets of natural isotopic abundance were bombarded by protons from a Van de Graaff generator, and the electric monopole internal conversion electrons detected using an intermediate image spectrometer. The excitation curves are characterized by many narrow resonances superimposed on a continuously increasing yield. The $L+M$ and the K internal conversion electrons have been resolved for these transitions using 0.50% resolution. The ratio of K to $L+M$ electrons is 7.85±0.10 for Ge^{72} and 6.84±0.20 for Zr^{90}. The continuous positron and negatron spectra of the competing pair decay mode from the 1.75 Mev Zr^{90} state have been observed. Comparison of the number of positrons with the number of conversion electrons gives a preliminary value of 2.76±0.20 for (W conversion/W pair). The error lies almost entirely in uncertainties of background subtraction.

* This work partially supported by the U. S. Atomic Energy Commission.

UA3. Evidence for Pickup Mechanism in $Nb^{93}(p,\alpha)Zr^{90}$. CHARLES D. GOODMAN, *Oak Ridge National Laboratory.**—Experiments at this laboratory with 22-Mev protons have shown that (p,d) and (p,t)[1] reactions proceed by the pickup of one and two neutrons, respectively, and that final states having shell configurations similar to the target are strongly favored. Furthermore, in the (p,t) case, pickup of two neutrons from the same shell is favored over pickup of neutrons from from different shells. The high-energy end of the alpha spectrum from $Nb^{93}(p,\alpha)Zr^{90}$ was examined to look for a possible contribution to the (p,α) reaction from a similar mechanism. The round state transition was observed, which in itself indicates the presence of a direct interaction, since this transition should have been many orders of magnitude weaker if the reaction proceeded only through a compound nucleus. The ground state could be reached by the pickup of a $g_{9/2}$ proton and a pair of $d_{5/2}$ neutrons. Pickup of a $g_{9/2}$ proton with a pair of $g_{9/2}$ neutrons should, however, be favored and should result in a residual excitation of about 4 Mev. Indeed a peak in the alpha spectrum appears at that energy, and with the present poor statistics looks to be about eight times as strong as the ground state peak at 20-deg lab angle.

[1] C. D. Goodman and J. B. Ball, Bull. Am. Phys. Soc. Ser. II, **4**, 9 (1959); J. B. Ball and C. D. Goodman, *ibid.* Ser. II, **4**, 287 (1959).

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.

UA4. Inelastic Scattering Reactions of In^{115} and Cd^{111} with Alpha Particles, Deuterons, and Protons.* NORBERT T. PORILE, *Brookhaven National Laboratory.*—The excitation of $In^{115}(I=(9/2)+)$ and Cd^{111} $(I=\frac{1}{2}+)$ to their respective isomeric states (4.5-hr In^{115m}—$I=\frac{1}{2}-$, 49-min Cd^{111m}—$I=(11/2)-$) has been studied. Excitation functions for these reactions have been obtained for bombardment by 15–40 Mev alpha particles, 10–20 Mev deuterons, and 5–10 Mev protons. The maximum values of the cross-sections measured for the (α,α'), (d,d'), and (p,p') reactions on In^{115} are 6 mb, 42 mb, and 3 mb, respectively. In all cases the cross sections increase monotonically with bombarding energy. The cross sections for the foregoing reactions will be compare with the cross sections for the same reactions on Cd^{111} and the effect of the differences in spin will be considered. The observed cross sections will be compared with values calculated on the basis of compound nucleus and direct-interaction mechanisms. Excitation functions have also been measured for the $In^{115}(\alpha,\alpha n)In^{114m}$ and $In^{115}(\alpha,\alpha n)In^{114g}$ reactions in order to aid in the interpretation of the previously discussed reactions. The value of σ_m/σ_g obtained at 40 Mev is 0.7.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

UA5. $Ce^{140}(d,p)Ce^{141}$ Reaction. H. J. MARTIN AND G. B. HOLM,* *Indiana University.*—Natural cerium targets (88.5% Ce^{140}, 11.1% Ce^{142}) were made by evaporation and were bombarded with 10.7-Mev deuterons from the Indiana University cyclotron. The outgoing protons were analyzed by a 180° double focusing magnetic spectrometer and distinct proton groups ascribed by the Ce^{140} (d,p) Ce^{141} reaction, were found at Q values of 3.22, 2.56, 2.09, 1.75, 1.46, 1.12, and 0.82 Mev. Definite groups could not be resolved at lower Q values. Angular distributions were measured for the seven observed groups at laboratory angles between 12.5 deg and 135 deg. The angular distributions will be presented and the proton groups will be discussed as possible single-particle levels of the 83rd neutron.

* On leave from the Nobel Institute of Physics, Stockholm.

UA6. Nucleon Transfer in the $Au^{197}(N^{14},N^{13})Au^{198}$ Reaction.* J. A. MCINTYRE, F. C. JOBES, AND T. L. WATTS, *Yale University.*—N^{13} nuclei from the $Au^{197}(N^{14},N^{13})Au^{198}$ reaction have been detected as a function of angle with respect to the direction of the N^{14} beam for various N^{14} bombarding energies. The N^{13}-production differential cross section is found to be a maximum at a center-of-mass angle ϕ_{max}, corresponding to an N^{14} classical trajectory grazing the Au^{197} nucleus and transfering a neutron to the Au^{197} nucleus. Such a description of the process is verified by the experimental relationship between ϕ_{max} and E_{cm}, the energy in the center-of-mass system. Integration of the angular distribution data also yields a total cross section for the transfer process as a function of energy.

* Supported by the U. S. Atomic Energy Commission.

UA7. Elastic Scattering of Protons by Single Isotopes. CLYDE B. FULMER, *Oak Ridge National Laboratory.**—Relative differential cross sections for the elastic scattering of 22.4-Mev protons were measured for Mn^{55}, Fe^{57}, Ni^{64}, Zn^{64}, Nb^{93}, Rh^{103}, Cd^{116}, Sn^{116}, Ta^{181}, and Au^{197} at $\sim 2\frac{1}{2}$-deg intervals over the angular range of 20–150 deg. Cross sections for elastic scattering of 16.4- and 9.5-Mev protons were also measured for Ni^{64} and Zn^{64} at $\sim 2\frac{1}{2}$-deg intervals over the angular range of 25–120 deg. The collimated external beam of the ORNL 86-in. cyclotron was passed through thin target foils at the center of a 24-in. scattering chamber. Scattered protons were detected by a NaI(Tl) scintillation counter; pulse-height analysis was used to identify the elastically scattered protons. The 22.4-Mev data indicate that the positions of minima and maxima of the elastic scattering angular distributions are not appreciably influenced by closed proton shells nor by variation of the nuclear symmetry parameter, $(N-Z)/A$. The 9.5-Mev data for Ni^{64} and Zn64, however, show differences in the positions of maxima and minima of the elastic scattering angular distributions; these are consistent with a dependence of real nuclear potential well depth on $(N-Z)/A$.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.

UA8. Elastic Scattering of 27.3-Mev Nitrogen by Aluminum. A. ZUCKER AND M. L. HALBERT, *Oak Ridge National Laboratory.**—The differential cross section for elastic scattering of 27.3 Mev nitrogen-14 ions from aluminum was measured from 40° to 134° in the center-of-mass system. A coincidence system detecting both the nitrogen and the aluminum ion was used to identify the elastic events. The angular resolution was about ±1°. The ratio of the elastic cross section to the Coulomb cross section exhibits a small rise above unity around 50° c.m. and then drops almost exponentially from 60° to 134° c.m. where it has a value of 0.0265. The results of the experiment are compared with the Blair sharp cutoff model. Fair agreement is obtained from 30° to 96° c.m. with an interaction radius $R=9.07$ f. If we define $R=r_0(A_1^{\frac{1}{3}}+A_2^{\frac{1}{3}})$, the value of r_0 is 1.68 f. Beyond 96° c.m. the sharp cutoff calculation displays increasing oscillations and no longer fits the data. The results of a semiclassical scattering theory due to Ford and Wheeler[1] are also compared with the experimental data. Good agreement is obtained between this theory and experiment from 95° to 134° c.m. for a rainbow angle $\theta_r=94°$, and a nuclear surface thickness parameter $\Delta R=0.83$ f.

* Operated for U. S. Atomic Energy Commission by Union Carbide Corporation.

[1] K. W. Ford and J. A. Wheeler, Ann. Phys. **7**, 259 (1959).

UA9. Optical Model Analysis of Heavy Ion Scattering. R. H. BASSEL, R. M. DRISKO,* *Oak Ridge National Laboratory,*† AND M. A. MELKANOFF, *University of California at Los Angeles.*—Theoretical studies were made of the elastic scattering of nitrogen ions from carbon at laboratory energies of 27.3, 23.5, and 21.5 Mev; and of nitrogen scattering from beryllium at a laboratory energy of 273. Mev. Fair agreement between theory and experiment is found in the forward direction ($\theta_{cm}<90°$). The analysis was made using either volume absorption or surface absorption. Volume absorption gives parameters similar to those found in analyses of nucleon-

nucleus collisions. With surface absorption more physically reasonable parameters (for these processes) are found.

* Permanent address: University of Pittsburgh.
† Operated for U. S. Atomic Energy Commission by Union Carbide Corporation.

UA10. Gamma-Ray Resonance Scattering Studies with the Livermore Linear Accelerator.* F. D. SEWARD, H. W. KOCH,† R. E. SHAFER, AND S. C. FULTZ, *Lawrence Radiation Laboratory, Livermore.*—The Livermore linear electron accelerator has been used to study the spectra of scattered gamma rays from several elements. Bremsstrahlung x-rays were produced by a beam of 20-Mev electrons striking a Ta target. Electron beam currents of about 10 μamp were used. These x-rays were scattered by a sample placed 2 ft in front of the Ta target. The gamma ray detector was set up 15 ft from this sample at a scattering angle of 90°. A 6×5 in. diam NaI(Tl) crystal was used as a detector. Gamma rays entering this crystal were collimated by a 1-in. diam hole in the Pb shield. Spectra of gamma rays scattered from Li, B, C, O, Mg, and Si will be shown. Resonant-scattered gamma rays are observed at energies of 3.6 Mev from Li^6; 4.5, 5.1, 7.3, and 8.9 Mev from B^{11}; 15.1 Mev from C^{12}; 6.9 Mev from O^{16}; 9.4 and 11.2 Mev from Si; and 10.5 Mev from Mg. Interpretation of these spectra will be discussed.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† National Bureau of Standards.

UA11. Incoherent Scattering of 0.662-Mev Gamma Rays.* J. V. JOVANOVICH, *Washington University,* AND J. P. HURLEY, *U. S. Naval Radiological Defense Laboratory.*—An intense collimated beam of 0.662-Mev gamma rays produced by a 130 curie Cs^{137} source was used to measure the scattering from thin targets of pure gold, silver, and copper. The scattered radiation was measured simultaneously at four different angles, 60°, 90°, 120°, and 150°. The experimental results will be compared with the existing theoretical cross sections for incoherent[1] and coherent[2] scattering.

* Supported in part by the National Science Foundation and the U. S. Air Force Office of Scientific Research.
[1] J. Randles, Proc. Roy. Soc. (London) **A242**, LXX, 337 (1957).
[2] G. E. Brown and D. F. Mayers, Proc. Roy. Soc. (London) **A242**, 89 (1957).

SATURDAY MORNING AT 9:15

New Yorker Grand Ballroom

(L. H. FISHER presiding)

Electron Physics

V1. Low-Lying Characteristic Energy Loss in Aluminum.* M. D. WAGNER, L. MARTON, AND J. AROL SIMPSON, *National Bureau of Standards.*—The energy spectrum of 20-kev electrons scattered by aluminum was measured in order to ascertain the value of the low-lying characteristic energy loss oxide-free aluminum films. The aluminum films were prepared in the dynamic vacuum of the velocity analyzer used to obtain the scattering data. In order to obtain oxide-free films, other materials were deposited before and after the aluminum evaporation forming a "sandwich" film. These evaporations were performed in rapid succession. The resulting value for the low-lying aluminum loss gives support to the value of 10 ev predicted by Stern[1] and found by Powell and Swan.[2] The energy loss spectrum of aluminum films deposited on gold films and immediately placed in the path of a 20-kev electron beam also supports Stern's value. When this same aluminum-gold film was exposed to oxidation and remeasured, the value was lowered to 7 ev.

* Supported in part by the U. S. Atomic Energy Commission.
[1] E. A. Stern, Bull. Am. Phys. Soc. Ser. II, **4**, 235 (1959).
[2] C. J. Powell and J. B. Swan, Phys. Rev. **115**, 869 (1959); also private communication of more recent results.

V2. Poisson Distribution in the Forward Characteristic-Loss Scattering of Electrons from Aluminum at 20 kev.* H. A. FOWLER, L. MARTON, J. AROL SIMPSON, J. A. SUDDETH, AND M. D. WAGNER, *National Bureau of Standards.*—The peak areas of the characteristic-loss energy distribution have been compared with the Poisson distribution function suggested by Blackstock, Ritchie, and Birkhoff.[1] The method of curve fitting subtracts out a continuous inelastic background. Five- and six-point fits have been obtained for arguments of the Poisson function ranging from 0.45 to 1.40. The arguments thus obtained agree with the ratio of specimen thicknesses determined by the Tolansky interferometer method. Application of these results to the determination of mean free path will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Blackstock, Ritchie, and Birkhoff, Phys. Rev. **100**, 1078 (1955).

V3. Characteristic Energy Losses and Optical Transmissivity.* H. MENDLOWITZ, *National Bureau of Standards.*—Weissler *et al.*[1] have measured the reflectivities and transmissivities of a number of materials as a function of wavelength through the vacuum ultraviolet. In general, they have found that the onset of transmission in metal films occurs at a photon energy which is slightly less than the energy loss suffered by the electron in the major characteristic loss. A correlation of these phenomena will be made in terms of the complex dielectric constant as a function of frequency.[2] Also, the general form of the transmissivity curves will be interpreted in terms of the dielectric constant.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Rustgi, Walker, and Weissler, Bull. Am. Phys. Soc. Ser. II, **4**, 226 (1959); Walker, Samson, and Rustgi, J. Opt. Soc. Am. **48**, 71 (1958).
[2] Marton, Leder, and Mendlowitz, *Advances in Electronics and Electron Physics* (Academic Press, Inc., New York, 1955) Vol. 7, p. 183.

V4. Electron-Electron Collision Interpretation of Characteristic Energy Losses in Solids. E. J. STERNGLASS, *Westinghouse Research Laboratories.*—The dependence of the principal electron energy losses on angle of scattering θ has been regarded as conclusive evidence for the excitation of plasma oscillations in solids.[1,2] It will be shown that the same behavior is predicted if these losses are assumed to accompany the ionization of electrons in shells next to the outermost, bound with an energy I_0 of the order of $\hbar\omega_{pl}$, the theoretical plasmon energy. Momentum and energy conservation leads to the following relation for θ in terms of incident energy E_i and final energy E_f: $\cos\theta=[E_f+(1/2)I_0][E_fE_i]^{-\frac{1}{2}}$.[3] Under typical conditions ($E_i\gg I_0$; $E_i-E_f=\Delta E_i\ll E_i$ and $\sin\theta\simeq\theta$) this expression reduces to $\theta^2=(\Delta E_i/E_i)-(I_0/E_i)$, compared with $\theta^2=(2\alpha)^{-1}(\Delta E_i/E_i)-(\hbar\omega pl/E_i)$ derived from plasma theory, where $\alpha=0.45$ for Al.[1] Since measurements on Al films give $\alpha=0.50\pm0.05$,[1] they are consistent with either interpretation. As shown elsewhere,[4] the remaining aspects of the characteristic losses can also be explained in terms of individual excitation and ionization

processes, so that this phenomenon may be understood without introducing any collective interactions.

[1] H. Watanabe, J. Phys. Soc. Japan **11**, 112 (1956).
[2] D. Pines, Revs. Modern Phys. **28**, 184 (1956).
[3] Mohr and Nicoll, Proc. Roy. Soc. (London) **A144**, 596 (1934).
[4] E. J. Sternglass, Nature **178**, 1387 (1956).

V5. Relation between Electron Energy Dissipation and Secondary Emission in Solids. HELMUT KANTER, *Westinghouse Research Laboratories.*—Electron penetration experiments on thin films of C and Al at energies below 10 kev,[1] augmented by similar measurements in the backward direction, permit a determination of the energy dissipation as a function of depth. While at low primary energies, the rate of energy loss per unit foil thickness, dE/dx, is roughly constant in the first half of the practical range,[2] with increasing energy dE/dx shows an increasingly pronounced maximum at about one-half the practical range. It will be shown that a direct proportionality exists between dE/dx at the surface and the yield of secondary electrons (SE). Per SE emitted, dx/dE was found to be 2.7 ev/A in Al and 4 ev/A in C. The actual energy expended per SE formed in the solid calculated from this data depends on SE escape depth and surface transmission. For sufficiently high energies, the energy dependence of the yield of SE was found to approach that of the rate of energy loss per unit path-length calculated from the Bohr-Bethe theory. With decreasing energies, the SE yield increases more rapidly, revealing the importance of primary scattering in SE production.

[1] H. Kanter, Bull. Am. Phys. Soc. Ser. II, **4**, 420 (1959).
[2] J. R. Young, J. Appl. Phys. **28**, 524 (1957).

V6. Hot Electron Emission from Silicon.* W. E. SPICER, *RCA Laboratories.*—Burton has reported electron emission from a back biased *p-n* junction in silicon which has received a Cs surface treatment. For convenience we will term this emission "hot electron emission" (HEE). We have obtained similar results using a somewhat different Cs surface treatment. The Si surface is degassed by heating to 775°C and then exposed to Cs vapor while the tube is held at about 110°C. There are indications that the optimum surface coverage approaches a monolayer. The photoemissive quantum efficiency from these Cs treated Si surfaces is about 10^{-4} electron/photon at 1.5 ev and sometimes rises to 6×10^{-3} electron/photon at about 3.6 ev. The threshold of photoemission is fairly insensitive to surface coverage, but the peak response increases with increasing surface coverage. The shapes of our plots of HEE current *versus* applied voltage are similar to those of Burton; however, peak currents in excess of an ma are obtained in comparison to Burton's value of <0.1 ma. The apparent saturation of emission current with voltages greater than about 70 v is shown to be due to the IR drop of the Si in series with the junction. This apparent saturation disappears if corrections are made for this effect and it can be shown that emission currents greater than an ma are actually obtained for junction voltages of less than 40 v.

* Work supported in part by the United States Signal Corps.

V7. Mobile Acceptor Model for Oxide-Coated Cathodes.* EUGENE B. HENSLEY AND KOJI OKUMURA, *University of Missouri.*—The diffusion of the activation in oxide-coated cathodes has been measured by observing the profile of the thermionic emission along a cathode coated on a ribbon of pure platinum. A peaked initial distribution was obtained by inserting a small tab of active cahtode nickel at the center of the ribbon. The diffusion coefficient at 1000°K was found to be 3×10^{-7} cm^2 sec^{-1} with an activation energy of 0.4 ev. This diffusion is consistent with the diffusion of barium ion vacancies[1] assuming that the ratio of these vacancies to the barium ion lattice sites is of the order of 10^{-5}. A mobile *acceptor* model for oxide-coated cathodes is proposed in which the principle donors are oxygen ion vacancies. Since these have a very low-diffusion coefficient,[2] their number will remain relatively unchanged during normal activation or deactivation processes. Activation of an oxide coated cathode is achieved not by increasing the density of donors but by decreasing the density of acceptors, the barium ion vacancies. This process will be governed by the rate at which these barium ion vacancies diffuse to a source of excess barium. The familiar m-decay phenomenon is accounted for by drift of the positively charged acceptors.

* Supported in part by the Office of Naval Research.
[1] R. W. Redington, Phys. Rev. **87**, 1066 (1952).
[2] Sproull, Bever, and Libowitz, Phys. Rev. **92**, 77 (1953).

V8. Temperature Variations of Oxide Cathodes in Commerical Tubes. G. MESNARD, G. DÉJARDIN, AND R. UZAN, *Université de Lyon.*—A study has been made of the temperature variations arising at the coating surface and in the nickel base when the thermionic current is set to some definite value. With a new tube, of which the cathode is just activated, a cooling effect and a subsequent rise of temperature are observed; the former is weaker and the latter is higher for the base than for the surface. The rise of the base temperature lessens if the tube has been moderately aged; it is still more reduced after a prolonged aging (several hundreds of hours) and is then followed by a slow fall, which is particularly marked at high temperature. This decline does not occur at the coating surface, where the effect of the aging is not so prominent. The experimental results show that the resistance of the oxide layer, which depends on the current, is not uniform across the coating and decreases during the first part of the tube life. They sustain the views of Metson regarding the influence of gases present within the porous coating and the mechanism of electron transfer.

V9. Study of KCl on Tungsten by Field-Emission Microscopy. M. SILVER AND R. S. WITTE, *University of Notre Dame.*—KCl was deposited onto a tungsten point and the kinetics of KCl on tungsten studied as a function of time and temperature. Directional deposition of KCl on tungsten at 302°K showed a symmetrical pattern rather than a pileup indicating KCl readily migrates across the tungsten surface. The contaminated point was heated to various temperatures and the resulting patterns and related average work functions were observed. The time to go from one stable pattern to another was recorded as a function of temperature. Plots of ln$t$ *vs* $1/T$°K were made and a straight line in two temperature ranges, 1150°K to 1350°K and 1780°K to 1950°K, was obtained. The slopes yielded activation energies of 92(kcal/mole) and 74(kcal/mole,) respectively. It is believed that KCl is dissociated and the potassium is desorbed at temperatures below 1100°K, and that the lower temperature range-activation energy corresponds to the formation of a tungsten chloride The higher temperature-activation energy is believed to correspond to a desorption of the chloride leaving clean tungsten as the final state.

* Work supported by Office of Naval Research.

V10. Electroluminescence under Pulsed Square-Wave Excitation. R. ZALLEN,* W. T. ERIKSEN, AND H. AHLBURG, *Raytheon Research Division.*—The slow return of an electroluminescent cell to its equilibrium state following a field excitation has been studied for a blue-green emitting Zn(S,O):Cu, Cl phosphor and for a yellow-emitting AnS:Mn, Cu phosphor. The light pulse emitted upon the rise of a square-voltage pulse was measured as a function of repetition rate and of temperature between −130°C and 150°C. Relaxation times encountered varied from 10^{-2} sec to more than 10^5 sec. The temperature dependence of the relaxation rate exhibits effective activation energies of about 0.4, 0.7, and 0.6 ev, respec-

tively, for the blue, green, and yellow emission bands. The results do not seem to favor the mechanism of delayed recombination. An alternative mechanism is suggested whereby the number of filled deep donors is assumed to control the electroluminescence emission via the number of field-ionizable electrons available for collision-excitation of centers. Observations were also made on some other effects associated with square-wave excitation.

* Now at Gordon McKay Laboratory, Harvard University.

V11. Irreversible Thermodynamics of Injection Electroluminescence. FERD E. WILLIAMS, *General Electric Research Laboratory.*—The possible generation by minority carrier injection of electroluminescent emission exceeding the electrical input has been suggested.[1,2] The additional energy would be taken as heat from the lattice and the system would thereby cool. Equilibrium thermodynamics has been applied to the problem and tends to support the possibility.[3] Injection electroluminescence can readily be shown to be irreversible. The application of irreversible thermodynamics provides more severe limitations on the efficiency of injection electroluminescence. Because the second law must be satisfied locally for irreversible processes[4] the entropy increase associated with the radiation must at least balance the entropy decrease accompanying electron-hole pair annihilation. This requirement precludes quite generally realistic electroluminescent emission intensities in excess of the electrical input. Radiative recombination at impurities introduces additional limitations. The thermodynamic limitations which are common to both electro- and photoluminescence will be discussed.

[1] J. Tauc, Czechoslov, J. Phys. **7**, 275 (1957).
[2] R. N. Hall (private communication).
[3] M. A. Weinstein (to be published).
[4] I. Prigogine, *Thermodynamics of Irreversible Processes* (Charles C Thomas, Springfield, Illinois, 1955), p. 17.

V12. Fatigue in Electroluminescent Phosphors.* S. NUDELMAN AND J. MUDAR, *University of Michigan.*—Fatigue in electroluminescent phosphor panels (decrease of electroluminescence (*el*) under constant operating conditions) has been observed at frequencies up to 6 mcps, with applied voltages up to 1500 v across a 4-mil thick cell. Fatigue is accelerated with increasing frequency, so that a 2 mcps, *el* diminishes from 10 to 25% of initial values within 30 minutes. Fatigued phosphors show a decrease in time average light output at the higher frequencies. Mechanically shaking a phosphor-air *el* cell after fatigue causes a partial restimulation of *el*, followed by fatigue. Successive shakes show a decreasing effect corresponding to all sides of the phosphor particle being fatigued. This indicates a uniform filling of deep surface traps, or a uniform degradation in *el* centers. Tests for deep traps using high voltage,—low frequency fields simultaneously with photostimulation were negative. Measurements on phosphor in air and in various dielectrics indicate with Roberts[1] that fatigue is characteristic of the phosphor although his law is not confirmed. Appreciable fatigue occurs for cells operated down to liquid nitrogen temperatures.

* This work was conducted by Project Michigan under the Department of the Army contract administered by the United States Army Signal Corps.
[1] S. Roberts, J. Appl. Phys. **28**, 262 (1957).

V13. Ionic Properties of Electroluminescent Zinc Sulfide. MAXWELL RATNER, *IBM* (introduced by J. M. Engel).—By the use of a photographic technique,[1] simultaneous measurements of the instantaneous capacity and conductivity as functions of temperature (T), the maximum value of the applied voltage (V_m), and the frequency (f) were made on dielectric cells of electroluminescent ZnS:Cu:Cl. This material behaves like a highly ionic semiconductor. The conductivity (σ) follows the high-field ionic relationship: $\sigma=[N(ea)^2\nu/kT]\times\exp(-E/kT)]\cosh|(ae/2lkT)V_m\sin(2\pi ft)|$, where N is the concentration of lattice defects, a is the jump distance, ν is the characteristic lattice frequency, e is the electronic charge, and l is the effective thickness of the cell. Experimentally found values are in agreement with those determined by other investigators:[2,3] $\sigma\sim10^{-9}$ ohm^{-1} cm^{-1}; $N\sim10^{17}$ per cm^3; $\nu=7\times10^7$ cps; $E=0.28$ ev; $a=2\times10^{-6}$ cm. The energy of the defects is $\sim5kT$ at high fields for these cells. Dielectric relaxation peaks are present at 1.5 and 30 kc, and in the neighborhood of 1–10 cps. The low-frequency peak is ascribed to the action of ultraviolet light, and the 1.5-kc peak is associated with the emission of green light. The mechanism responsible for the 30-kc peak has not been identified.

[1] M. Ratner, Bull. Am. Phys. Soc. Ser. II, **4**, 370 (1959).
[2] A. N. Ince and C. W. Oatley, Phil. Mag. **46**, 1081 (1955).
[3] W. A. Thornton, Phys. Rev. **102**, 38 (1956).

SATURDAY MORNING AT 9:30

Statler-Hilton Ivy Suite

(A. M. SACHS presiding)

Pions

VA1. Low-Energy Photoproduction of Neutral Pions from Complex Nuclei.* R. A. SCHRACK,† *National Bureau of Standards and the University of Maryland,* AND S. PENNER AND J. E. LEISS, *National Bureau of Standards.*—Angular distribution measurements have been made of neutral pion photoproduction from C, Al, Cu, Cd, and Pb using 170-Mev bremsstrahlung. The pion decay photons were detected in coincidence. The observed angular distributions show a diffraction pattern whose first fall-off agrees well with Born approximation predictions based on coherent production from nuclear matter distributions having the same half density radius as that of the charge distributions determined by electron scattering. The second maxima of the diffraction patterns differ from the Born approximation predictions, the lower A nuclei having the second maxima increasingly enhanced. Analysis of the data has not been completed but the ratio of the observed counting rate to a Born approximation prediction goes as $A^{1.65}$ where a simple coherent production model yields a ratio of A^2.

* Supported in part by U. S. Atomic Energy Commission Division of Research.
† Based in part on work for a Ph.D. thesis, University of Maryland.

VA2. Photoproduction of Neutral Mesons from Complex Nuclei. G. DAVIDSON, D. LUCKEY, AND L. S. OSBORNE, *M.I.T.*—The photoproduction of neutral mesons by 250-Mev gamma rays has been studied using an energy sensitive yoke counter. The angular resolution for mesons produced at 0° is ±5.3°. Measurements were made from C, Al, Ca, Ti, V, Cu, Cd, and Pb and the results normalized to hydrogen. The observed angular distributions show a small cross section at 0°, rising

to a peak at angles of about 20° and then decreasing. This is in agreement with an optical model calculation which predicts a form factor multiplied by the fundamental production cross section ($\sim\sin^2\theta$). The measurements can be used to obtain a nuclear radius $r_0=(1.09\pm0.03)\times10^{-13}$ cm $A^{\frac{1}{3}}$ and a value for the imaginary potential of 60 ± 15 Mev. Attributing the deviations at forward angles to an inverse π_0 lifetime effect yields a lower limit for the lifetime $\tau>5\times10^{-18}$ sec.

VA3. Charged Pion Production by 200 Mev Photons from Hydrogen and Deuterium.* R. Fessel and T. R. Palfrey, Jr., *Purdue University.*—Measurements have been made of the minus-plus ratio from deuterium and the ratio of positive pion production in deuterium and hydrogen by 200-Mev photons. The target is a 2-in diam thin-walled container filled with either liquid hydrogen or liquid deuterium; the photon source is the bremsstrahlung beam of the Purdue synchrotron. The pions are momentum analyzed by a 120° double-focusing spectrometer and detected by a triple coincidence counter array which counts pions in 5 contiguous momentum channels, each 4.4% wide. Measurements have been made for one set of pion momenta at 90° c.m. at 10 different peak bremsstrahlung energies for both hydrogen and deuterium. The data indicate that the minus-plus ratio for fixed pion energy and angle is a function of the photon energy. Measurements are being continued at 45° and 135° c.m. angles at the corresponding pion energies. The implications of these results with respect to previous experiments will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.

VA4. Charged Pion Photoproduction from Carbon.* H. R. Fechter, B. M. K. Nefkens, and T. R. Palfrey, Jr., *Purdue University.*—The spectrometer magnet described in the preceding abstract has been used to measure charged pion photoproduction from carbon at the same meson energies and angles as those used for deuterium and hydrogen. The yield has been measured at 7 different peak bremsstrahlung energies. Minus-plus ratios have been obtained to an accuracy of about 5%. Measurements are being extended to other angles and pion energies.

* Supported in part by the U. S. Atomic Energy Commission.

VA5. Photoproduction of Charged π Mesons from Nuclei.* W. M. McClelland, *Cornell University.*—Charged π mesons have been produced from the elements Be, C, Al, Cu, and Pb by a 1.0-Bev bremsstrahlung beam of the Cornell synchrotron. They are momentum analyzed by a strong focusing magnet and then identified by pulse height in a three-counter telescope. The ejection of protons is facilitated by the use of suitable absorber. A lead glass Čerenkov counter is used to eliminate electrons when necessary. In this way the production of both π^+ and π^- mesons has been measured at two laboratory angles, 58° and 115°, for several laboratory kinetic energies in the range from 100 to 400 Mev. For a free nucleon these angles correspond to 90° and 135° in the center of mass system for a photon energy of 1 Bev. Preliminary analysis of the data indicates an A dependence near $A^{\frac{1}{3}}$ for both π^+ and π^-. Values of the cross section will be presented together with π^-/π^+ ratios.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

VA6. Electroproduction of Pions on Hydrogen and Deuterium.* G. Ohlsen, *Stanford University.*—The absolute cross section for direct production of pions in electron-proton, electron-deuteron collisons has been measured. The methods used were similar to those used by Panofsky and Allton.[1] The proton data have been extended over the range $q^2=2.6$ fermi^{-2} to $q^2=10.75$ fermi^{-2} and center of mass energy $E=1100$ Mev to $E=1300$ Mev. Data analysis has been in terms of a neutron magnetic form factor. Comparison with the calculations of Gartenhaus and Lindner,[2] who used an approximation to the dispersion theoretical matrix element of Fubini, Nambu, and Wataghin,[3] yields a neutron magnetic moment radius of 1.0 ± 0.1 fermi. Better approximations to the theory may change this value somewhat. Analysis of the deuteron data is more difficult, primarily due to the initial nucleon momentum distribution and the four-body final state. The ratio of the electron-deuteron cross section to the electron-proton cross section appears to be fairly independent of kinematic parameters, and has an average value of $1.58\pm.05$

* Supported by the joint program of the Office of Naval Research, the U. S. Atomic Energy Commission, and the Air Force Office of Scientific Research.

[1] W. K. H. Panofsky and E. A. Allton, Phys. Rev. **110**, 1155 (1958).
[2] S. Gartenhaus and C. N. Lindner, Phys. Rev. **113**, 917 (1959).
[3] Fubini, Nambu, and Wataghin, Phys. Rev. **111**, 329 (1958).

VA7. π^-—p Interactions at 220 Mev.* J. Deahl, M. Derrick, J. Fetkovich, T. Fields, and G. Yodh, *Carnegie Institute of Technology.*—Interactions of 220-Mev negative pions with protons have been observed using a 15-cm hydrogen bubble chamber in a 13 kilogauss magnetic field. Preliminary analysis, based on a double scan of 35 km of track, yields an elastic scattering total cross section of 16.8 ± 1.5 mb. 1348 elastic scatterings were seen with $|\cos\theta_{c.m.}|\leq0.8$. Two events of the type $\pi^-+p\rightarrow\pi^-+\pi^++n$ were observed, corresponding to a corss section of ~15 μb. The angular distribution of the elastic scattering and the total charge exchange cross section will be presented.

* Supported in part by the U. S. Atomic Energy Commission.

VA8. Panofsky Ratio.* Nicholas P. Samios,† *Nevis Cyclotron Laboratory and Brookhaven National Laboratory.*—π^- mesons were stopped in a hydrogen bubble chamber 12 in. in diam, 6 in. deep with a magnetic field of 5.7 kilogauss. Among the reactions observed were the following: $\pi^-+p\rightarrow\pi^0+n$ where $\pi^0\rightarrow\gamma+e^++e^-$; $\pi^-+p\rightarrow n+e^++e^-$, the first being the internal conversion of a γ ray from π^0 decay and the second the internal conversion of a γ ray from $n+\gamma$ reaction. A fiducial region and dip criterion reduced the number of usable events from 14 000 to 4000. A measurement of the momentum and energy of each pair allowed a separation of the 4000 events into the two above categories. Using these numbers and the internal conversion coefficient as calculated by Kroll and Wada,[1] one gets a Panofsky ratio of 1.67 ± 0.08. The distributions in y, the energy partition, and x^2 the virtual photon mass agree with the theoretical predictions for both reactions.

* Work performed under contract with the U. S. Atomic Energy Commission.
† Now at Brookhaven National Laboratory.
[1] N. Kroll and W. Wada, Phys. Rev. **98**, 1355 (1955).

VA9. Branching Ratio of the Electronic Decay of the Positive Pion.* T. Fujii, R. H. Miller, L. Tau, and H. L. Anderson, *University of Chicago.*—A new measurement of the branching ratio $\pi^+\rightarrow e^++\nu/\pi^+\rightarrow\mu^++\nu$ has been completed. A double focusing magnetic spectrometer was used to observe the spectra of electrons emitted in π decay and in μ decay. The scintillation pulses from the pion and its decay electron were recorded on a traveling wave oscilloscope. Timing and pulse height measurements were used to distinguish good events from accidentals. The total number of π-e events recorded in this experiment was 1343, of which 6% were accidentals and 5% were $\pi\mu e$ contamination. The branching ratio obtained from the areas under the π-e and μ-e distributions was $(1.18\pm0.08)\times10^{-4}$. This is close to the result expected for a universal V-A interaction. Berman's formula[1] with $\Delta E=10$ Mev, as is appropriate in our case, gives 1.20×10^{-4}. Our data also give for the mean life of π decay $\tau_\pi=(25.6\pm0.8)\times10^{-9}$ sec.

* Research under the joint sponsorship of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] S. M. Berman, Phys. Rev. Letters **1**, 468 (1958).

VA10. Stopping of π-Minus and K-Minus Mesons on Hydrogen in Nuclear Emulsion.* GEORGE A. BAKER, JR., *University of California, Berkeley, and Los Alamos Scientific Laboratory.*—We show that the experimentally observed fact that the number of K^- mesons stopping on hydrogen in nuclear emulsion is significantly larger than the number of π^- is consistent with other known properties of these mesons. We calculate the first-order perturbation theory partial Coulomb capture cross sections for K^- and π^- mesons on atomic hydrogen. The principal reason more K^- than π^- mesons stop on hydrogen in nuclear emulsion is that the zero energy π^--p cross section is anomalously low.

* Supported in part by the U. S. Atomic Energy Commission.

VA11. Meson-Absorption Method for Measuring the n-n Scattering Length.* KIRK W. MCVOY, *Brandeis University.*—Watson and Stuart[1] suggested in 1951 that the reaction $\pi^- + d \rightarrow 2n + \gamma$ might be used to investigate the n-n interaction by observing its effect on the photon spectrum. The effect is large and accurately calculable in terms of the n-n ^1S phase shift, but is difficult to detect experimentally because it is confined to the last few Mev of a 130 Mev spectrum. We wish to point out that the effect of the n-n interaction on the energy and angle distributions of the outgoing neutrons is also very pronounced, and that a measurement of one of these distributions seems a feasible means of determining the n-n scattering length to 10 or 20%. A coincidence measurement is required, to determine any two of the variables (such as an energy and a relative angle). The most promising distributions seem to be (a) the distribution of events over an n-gamma angle under the condition of equal neutron energies, or (b) the neutron spectrum at a fixed angle of about 175° to the photon direction.

* Supported in part by the National Science Foundation.
[1] K. M. Watson and R. N. Stuart, Phys. Rev. **82**, 738 (1951).

VA12. Photodissociation of Complex Nuclei at Energies between the Mesonic Threshold and 1143 Mev.* CHARLES E. ROOS, *University of California, Riverside, and California Institute of Technology* AND VINCENT Z. PETERSON, *California Institute of Technology.*—G-5 emulsions were exposed to the direct bremsstrahlung beam of the Caltech electron synchrotron. The photostar excitation curve was determined at a number of energies up to 1.15 Bev. Some 10 000 single and multiple pronged events in this and an earlier work were analyzed and compared with the total photo meson cross sections. The simple real meson model, which assumes the creation of a real meson and the subsequent inelastic scatter of either the pion or recoil nucleon, very adequately accounts for the observed photostar yields. The pion mean free paths in nuclear matter are obtained from the optical model analysis of pion scattering. The photostar cross section appears to be a convenient direct measure of the total photo meson cross section. The prong multiplicity is found to be a rough measure of the photon energy. Approximately 50 to 75 Mev/prong is required before the excitation function slopes upward to a significant degree. The visible energy release, prong angular distributions etc. were measured for 100 photostars (≥ 2 prongs) produced by 1150 Mev bremsstrahlung using an emulsion pellicle stack. The average visible energy shows a linear dependence on prong number. The angular distributions show noticeable forward peaking with increasing prong energy.

* Supported in part by the U. S. Atomic Energy Commission and the Research Corporation.

SATURDAY MORNING AT 9:30

New Yorker Terrace Room

(P. KUSCH presiding)

Invited Papers

W1. Resonant Scattering of Gamma-Rays in Solids, and Gravitational Red Shift. R. V. POUND, *Harvard University.* (30 min.)

W2. Nevis Neutron-Spectrometer Studies of Nuclear Resonance Parameters. JAMES RAINWATER, *Columbia University.* (30 min.)

W3. Atomic Motions in Water by Cold Neutron Scattering. D. J. HUGHES, *Brookhaven National Laboratory.* (30 min.)

W4. Crystal and Liquid Dynamics from Neutron Spectrometry. B. N. BROCKHOUSE, *Chalk River Laboratory.* (30 min.)

SATURDAY AFTERNOON AT 1:30

New Yorker Panel Room

(R. V. POUND presiding)

Magnetic Resonance

WA1. Magnetic Resonance of α-α-Di-Phenyl-Picryl-Hydrazyl in Fluid and Solid Media.* N. W. LORD AND S. M. BLINDER, *Applied Physics Laboratory, Johns Hopkins University.*—In a series of simple ESR experiments on DPPH radicals dispersed in fluid media of varying viscosity we have observed quantitatively the average isotropic and anisotropic hyperfine interaction associated with the two central nitrogen nuclei. The simple method employed here can be extended to many other radicals. The hyperfine interaction for strong field quantization is given by $[A + B(3\cos^2\theta - 1)]I_z S_z$. In fluid media the orienta-

tion-dependent B-term is averaged out by molecular tumbling more rapid than the hyperfine frequency. This results in a resolved 5-line ESR absorption characterized mainly by the A term which is -9 gauss. A residual broadening of each line is probably caused by momentary hindrances of the molecular tumbling and interaction with other nuclei. By using benzene, ethanol, silicone fluid, and Duco cement we covered a viscosity range up to several thousand centistokes without finding any variation in line shape. After Duco cement hardens the molecular tumbling virtually ceases and the ESR absorption dramatically changes shape. The shape is now dominated by large asymmetric distributions on the side lines due to the B-term. Analysis shows that $B \cong 11$ gauss. This result is in rough agreement with very detailed recent work by Holmberg.[1]

* Work supported by Bureau of Ordnance, Department of the Navy.
[1] R. Livingston (private communication).

WA2. Electron-Spin Resonance in Semiconducting Rutile.* P. F. CHESTER, *Westinghouse Research Laboratories.*—Electron spin resonance has been observed in single crystals of oxygen deficient TiO_2 at liquid helium temperatures. The spectrum is described by four magnetic sites with $S=\frac{1}{2}$, $g_s=1.940$, $g_z=1.972$, and $g_y=1.975$. The four z axes coincide and lie along the crystal c axis, while the four x (or y) axes make angles of approximately $\pm 25°$ with the crystal a axes. The single line observed with $H \| c$ axis has a full width of ~ 0.7 oe and is accompanied by a pattern of very weak satellites extending for 10 oe on either side. The spin lattice relaxation time at 2.16°K is 0.012 sec. No resonance could be seen at 77°K or at room temperature because of microwave losses which were observed to increase exponentially in the range 8°K to 12°K, with an activation energy of ~ 0.01 ev. Dc resistivity measurements on the same sample (10 ohm cm at 300°K) yielded the same activa-energy over the range from 5°K to 40°K by which temperature the resistivity had fallen to 0.1 ohm cm. An explanation of the paramagnetic center, in terms of Ti^{3+} associated with certain oxygen vacancies, will be discussed. No resonance was observed in oxygen deficient $SrTiO_3$ at liquid helium temperatures.

* Supported in part by the Air Force Cambridge Research Center.

WA3. Paramagnetic Resonance of Fe^{3+} in Rutile.* A. OKAYA, D. CARTER, AND F. NASH, *Columbia University.*—The electron spin resonance of the ${}^6S_{\frac{5}{2}}$, $3d^5$ ground state of Fe^{3+} in TiO_2 (Rutile) has been investigated experimentally. The local crystalline field is orthorhombic. The spectrum has been observed from 2 kmc to 120 kmc by a simple video type spectrometer using dielectric microwave resonators. The zero field splittings directly measured are 43.3 ± 0.1 kmc; $Ms=\frac{3}{2} \rightarrow \frac{1}{2}$, 81.3 ± 0.1 kmc; $Ms=\frac{5}{2} \rightarrow \frac{3}{2}$. The spectrum has been well explained by the constants:

$$D=+20.35 \pm 0.2 \text{ kmc} \quad E=+2.14 \pm 0.06 \text{ kmc}$$
$$a=+\ 0.8\ \pm 0.4 \text{ kmc} \quad g=\ 2.00 \pm 0.02 \text{ kmc}.$$

T_1 at 1.4°K was about 4 msec at X-band frequencies and less than 1 msec at K band. The saturation of 10^{19} spins was observed at 78°K, X-band frequency with only 0.1 mw power imput. This was caused by the high Q and high dielectric constant of the dielectric resonator. The line breadth varies between 3.5 to 15 gauss at X band depending upon the transition.

* Research supported by U. S. Air Force

WA4. Paramagnetic Resonance of Electrolytically Generated Free Radicals.* AUGUST H. MAKI, *Harvard University.*—Constant potential electrolysis at mercury and platinum microelectrodes has been applied to the generation of organic free radical ions directly within the microwave cavity of an X-band electron spin-resonance spectrometer. The resulting free radicals since present in a fluid solution exhibit a rich hyperfine structure the analysis of which can lead to the assignment of Fermi hyperfine coupling constants. Preliminary polarography of a solution of the neutral molecule reveals the potential required to reduce or oxidize the specie and whether the electrode process involves transfer of one or several electrons per molecule. If the study reveals a one-electron transfer, the resulting ion is a free radical which, if sufficiently stable, will give an electron spin resonance spectrum when the electrode process is carried out within the microwave cavity. The advantages of this method of generation of negative ion radicals over the conventional alkali metal reduction in solvents such as tetrahydrofuran will be discussed. Spectra obtained from the negative ions of nitrobenzene, ortho-, meta-, and para-dinitrobenzene generated by reduction at a mercury drop within the microwave cavity will be described.

* Supported in part by the National Institutes of Health and the National Science Foundation.

WA5. Paramagnetic Resonance of X-Irradiated Rochelle Salt.* G. C. MOULTON, W. G. MOULTON, AND W. B. ARD, JR.,† *University of Alabama.*—The paramagnetic resonance spectrum of Rochelle salt irradiated with 50 kv x-rays has been observed at 9000 Mc. The spectrum consists of at least 10 lines. The total width about the C axis is invariant and is 46 gauss with the center of the spectrum corresponding to a g value near 2. There is a small orientation dependence and data have been taken about all three crystalline axes. At least two sets of lines are present as indicated by the orientation dependence and the unequal decay rates of the components with time; one is a strong short-lived set, the other a weak long-lived set. The crystal becomes bright yellow after irradiation and the color and the anomalous hysteresis effects remain after the strong set of paramagnetic lines has decayed. The spectrum is the same whether observed above the ferroelectric Curie points or in the ferroelectric temperature range. It is concluded that the anomalous ferroelectric hysteresis effects found after irradiation are not due to the short lived paramagnetic centers.

* Supported by the U. S. Army Office of Ordnance Research.
† Present address: University of Florida.

WA6. Spin Coupling in Crystals with Two Paramagnetic Species.* A. KIEL, *The Johns Hopkins University Radiation Laboratory.*—In some recent work,[1] it has been shown that terms in the spin-spin interaction may lead to a diffusion of spins in frequency space. The reality of these effects is now well established in multi-level systems. By applying the rate equations, modified by the cross-coupling term, $-\frac{1}{4}g_i g_j \beta^2 r_{ij}^{-3} \times (1-3\gamma^2)[S_{+i}S_{-j}+S_{-i}S_{+j}]$ the effects of (nearly) overlapping resonance lines of different paramagnetic ions may be investigated. An effective relaxation time, observed in saturation experiments when only species α interacts with the rf field is shown to be

$$(T_1{}^\alpha)_{eff} = T_1{}^\alpha \frac{1+(N^\alpha/N^\beta)T_1{}^\beta(T_{21}{}^\alpha)^{-1}}{1+(N^\alpha/N^\beta)T_1{}^\beta(T_{21}{}^\alpha)^{-1}+(N^\beta/N^\alpha)T_1{}^\alpha(T_{21}{}^\beta)^{-1}}.$$

(See reference 1 for notation; set $T_{ad}=\infty$.) More general saturation expressions are derived and the pulse case is considered in detail. Estimates of the magnitude of the T_{21} based on lattice sum computations are presented for the cases $T_{21} \ll T_1{}^\alpha$, $T_1{}^\beta$ and $T_1{}^\beta < T_{21}{}^\alpha < T_1{}^\alpha$.

* Supported by the Wright Air Development Center, U. S. Air Force.
[1] N. Bloembergen *et al.*, Phys. Rev. **114**, 445 (1959).

WA7. Microwave Paramagnetic Resonance Spectrum of the Four Nonequivalent Cr^{+++} Sites in Doped $K_3Co(CN)_6$.* J. O. ARTMAN AND J. C. MURPHY, *Applied Physics Laboratory, The Johns Hopkins University.*—Investigations on the micro-

wave resonance of Cr^{+++} in single crystals of doped $K_3Co(CN)_6$ indicate the existence of *four* nonequivalent magnetic sites[1] rather than the *two* customarily described.[2] The effect is seen dramatically in the *b-c* crystal plane as a periodic splitting of supposedly single resonance lines into sets of three. The symmetry of the two additional resonances precludes their generation by simple crystal twinning. The microwave spectrum seems to be associated with the "polytypism" recently found in this crystal by Kohn and Townes,[3] which would predict four molecules per unit cell rather than two.[4] Further details and implications on maser performance will be presented. We would like to acknowledge the courtesy of J. Minkowski, Radiation Laboratory, Johns Hopkins University, in supplying us with samples.

* This work supported by Bureau of Ordnance, Department of the Navy.
[1] First reported at the Symposium on Solid State and Plasma Physics, Johns Hopkins University (November 3, 1959).
[2] Baker, Bleaney, and Bowers, Proc. Phys. Soc. (London) **B69**, 1205 (1956).
[3] J. A. Kohn and W. D. Townes, Acta Cryst. (to be submitted).
[4] V. Barkhatov and H. Zhdanov, Acta Physicochim. U.R.S.S. **16**, 43 (1942); V. Barkhatov, *ibid.* **16**, 123 (1942).

WA8. Inequality of the Knight Shift for Li^7 and Li^6.* M. P. KLEIN AND D. F. ABELL, *Lawrence Radiation Laboratory, Livermore.*—Simultaneous observation of the nuclear magnetic resonance of the two isotopes of lithium, Li^6 and Li^7, alternately in aqueous solution and in finely dispersed metal reveals that the Knight shift for the two isotopes is not the same. The difference in the shifts divided by one plus the shift for Li^6 is 2.64×10^{-6} at room temperature. Preliminary examination of this result shows that it can be accounted for if the factor P_F in the Knight shift formula differs for the two isotopes by about 1%. The departure of the nuclear g ratio in the metal from that in an ionic solution is equal to the value found by Feher[1] with Endor measurements on Li-doped silicon.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] G. Feher, Phys. Rev. **114**, 1219 (1959).

WA9. Nuclear Magnetic Resonance in Multidomain Ferromagnetic Cobalt Particles.* A. C. GOSSARD† AND A. M. PORTIS, *University of California, Berkeley.*—The effect of domain wall motion on the nuclear magnetic resonance of Co^{59} in 5 to 10 μ multidomain metallic cobalt particles has been studied. It is shown that the bulk of the resonance absorption arises from nuclei within the domain walls. From the extraordinary intensity of the initially observed cobalt resonance absorption, it was inferred that the rf magnetic field at the cobalt nuclei is much stronger than the applied rf field.[1] Saturation measurements now show directly the value of the rf field at the participating nuclei to be 1300 times the applied rf field. Domain rotation can produce an rf field enhancement no greater than 100. Domain wall motion, however, produces a larger enhancement than domain rotation by a factor of the ratio of domain diameter to domain wall thickness and satisfactorily accounts for the observed enhancement. Spin-spin and spin-lattice relaxation processes are interpreted with the wall motion mechanism and a nuclear spin interaction through spin waves as proposed by Suhl.[2]

* Supported by the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.
[1] A. C. Gossard and A. M. Portis, Phys. Rev. Letters **3**, 164 (1959).
[2] H. Suhl, Phys. Rev. **109**, 606 (1958).

WA10. Nuclear Magnetic Resonance Spectra of Halogenated Propane.* D. D. ELLEMAN, L. CARLTON BROWN, AND DUDLEY WILLIAMS, *Ohio State University.*—The magnetic resonance spectra of H^1 and F^{19} in various halogenated propanes have been investigated at room temperature. The experimental techniques employed were similar to those used in an earlier study of substituted ethanes.[1] Characteristic chemical shifts were determined for H^1 and F^{19} in various nonequivalent groups. Values of the observed shifts will be given and compared with those obtained in the ethane study. Values of the spin-spin coupling constants J were determined for various pairs of non-equivalent spin $\frac{1}{2}$ nuclei in each molecule. There is a general correlation between the magnitude of J and the proximity of the interacting nuclei; however, certain marked exceptions to this general correlation have been noted.

* Supported in part by the Office of Scientific Research, Air Research and Development Command, U. S. Air Force.
[1] Elleman, Brown, and Williams, Bull. Am. Phys. Soc. Ser. II, **4**, 418 (1959).

WA11. Proton Relaxation Times in H_2O-SiO_2 and H_2O-CuO Mixtures.* IRVING G. POST AND L. CARLTON BROWN, *The Ohio State University.*—Measurements of T_1 and T_2 have been made in water-solid mixtures in which the particle size of the solid was controlled. As expected, the value of T_2 decreases with decreasing particle size in H_2O-CuO more rapidly than in H_2O-SiO_2. The value of T_1 remains nearly constant except for the very small (0.05 mm) particle sizes; however, T_1 for H_2O-CuO is somewhat larger than for H_2O-SiO_2.

* Supported in part by the Office of Scientific Research, Air Research and Development Command, U. S. Air Force.

WA12. Quadrupole Coupling Constant of the Deuteron in HDS.* P. THADDEUS, J. LOUBSER,† AND L. KRISHER,‡ *Columbia University.*—A beam-type maser has been used as a microwave spectrometer to resolve the hyperfine structure of the $2_{20} \rightarrow 2_{21}$ rotational transition of the asymmetric top molecule HDS which lies at 11 283.8 Mc. The observed line widths of the various hyperfine components are approximately 5 kc/sec. Assuming symmetry of the electric field gradient tensor at the deuteron about the S—D bond, a value of 149 ± 10 kc/sec for χ, the quadrupole coupling constant along the bond, has been required to give a best theoretical fit to the observed spectrum. Substantial magnetic effects of both the H and D nuclei have also been detected.

* Work supported jointly by the U. S. Army Signal Corps, the Office of Naval Research, and the Air Force Office of Scientific Research.
† National Academy of Sciences Postdoctoral Fellow from University of the Orange Free State.
‡ National Science Foundation Postdoctoral Fellow.

WA13. Temperature Dependence of Frequency and Splitting of Nuclear Quadrupole Resonances in Solid Chlorine.* LANGDON T. CRANE, JR., AND ROY S. ANDERSON, *University of Maryland,* AND HUGH G. ROBINSON, *Yale University.*—Pure nuclear quadrupole resonances of Cl^{35} and Cl^{37} nuclei in solid, polycrystalline chlorine are observed under high resolution. The resonances consist of two components having intensity ratio 3:1. The separation of the components at 77°K is 3.3 kc for Cl^{35} and 2.8 kc for Cl^{37}. Observations of the Cl^{35} resonance have been made in the temperature range 77°K to 120°K. The frequency and splitting are essentially constant between 77°K and 88°K. Above 88°K the frequency decreases at the rate 8 kc/deg and the splitting decreases at 113 cps/deg. On the basis of observed intensity ratios the pairs of components may be attributed to either the mixed or pure isotopic nuclear species comprising the molecules. Specific heat data for solid chlorine indicate the presence of molecular vibrations in this temperature region. The stretching mode has been considered as a possible cause of the observed structure. A simple vibrating dumbbell model is used to calculate the effect of vibrational bond stretching on both frequency and splitting. Reasonable agreement with observations is obtained from the resulting relative bond elongation.

* Supported by the National Security Agency.

SATURDAY AFTERNOON AT 1:30

New Yorker Terrace Room

(R. J. PLANO presiding)

Muons; High-Energy Scattering

X1. Angular Distribution of Recoils from Muon Capture and Its Interaction. D. GREENBERG AND M. MORITA, *Columbia University.*—If a polarized muon is absorbed by a nucleus, the recoil has a certain angular distribution with respect to the muon polarization. The sign of this angular distribution will be a test of lepton conservation.[1] Using the theory of allowed and forbidden transitions in muon capture reactions,[2] we have studied this phenomenon theoretically, especially in connection with the induced pseudoscalar interaction and conserved vector current. A formula is given for the unique nth forbidden transition (spin change $\Delta J = |J_i - J_f| = n+1$, parity change $(-)^n$), with relativistic corrections. Numerical calculation on C^{12} gives the following results: 1. The relativistic matrix elements neglected in reference (1) have 5–20% effect. 2. The asymmetry coefficient depends strongly on the ratio of the induced pseudoscalar and axial vector coupling constants, but is rather insensitive to the assumption of conserved vector current.

[1] M. E. Rose and R. H. Good, Jr., Ann. Phys. (N. Y.) (to be published).
[2] M. Morita and A. Fujii, Bull. Am. Phys. Soc. Ser. II, **4**, 407 (1959).

X2. Decay Modes of the Muon. R. R. CRITTENDEN AND W. D. WALKER, *University of Wisconsin*, AND J. BALLAM, *Michigan State University.*—A 5 in freon (CF_3Br) bubble chamber was used to search for the following decay modes of the muon, (1) $\mu^+ \to e^+ + \gamma$. (2) $\mu^+ \to e^+ + e^- + e^+$. (3) $\mu^+ \to e^+ + \nu + \nu + \gamma$. (4) $\mu^+ \to e^+ + \nu + \nu + \nu + e^+ + e^-$. Approximately 3.5 10^5 π^+ mesons from the Carnegie Tech cyclotron were stopped in the fiducial volume of the chamber. The μ's from these π's were then scanned for the above decay modes. We have found no evidence for (1) and (2). Our results for the frequency of (3) and (4) are consistent with theory.

X3. Radiative μ-Capture in Hydrogen. GLENN MANACHER, *Carnegie Institute of Technology* (introduced by L. Wolfenstein).—Dye *et al.*[1] and others have pointed out that radiative capture of μ mesons in hydrogen is forbidden for "bare" V-A coupling if the system is in the singlet state before capture. If emission of inner bremsstrahlung does occur, it is the result of (a) the inequality of C_V and C_A for real nucleons, (b) emission by the neutron via its anomalous magnetic moment, (c) the "induced" pseudoscalar, (d) the Gell-Mann "weak" magnetic interaction. The pseudoscalar term is treated[2] by introducing a "catastropic" photon emission at the weak vertex, since the vertex operator is momentum dependent. The momentum-transfer dependence suggested by dispersion theory[3] in which a single pion intermediate state is responsible for the interaction, is assumed. We have also included a term required to make the Gell-Mann interaction gauge-invariant. Since practically all the observed radiative capture is due to renormalization effects, the observables in $\mu + p \to n + \gamma + \nu$ will be extremely sensitive to the renormalization constants, and may yield information on which renormalization effects are acutally present.

[1] Dye *et al.*, Sci. Sinica (Peking) **8**, 423 (1959).
[2] J. Bernstein, Phys. Rev. **115**, 694 (1959).
[3] M. L. Goldberger and S. B. Treiman, Phys. Rev. **111**, 354 (1958).

X4. Depolarization of Negative Muons in Liquid Helium.* R. PREPOST, V. W. HUGHES, AND S. PENMAN, *Columbia University*, AND D. MCCOLM AND K. ZIOCK, *Yale University.*—The depolarization of negative muons stopped in liquid helium has been measured in an experiment similar to that of Garwin, Lederman, and Weinrich.[1] The target, which contained 1.7 g/cm² of helium, was made from copper, stainless steel, and brass. The lifetime of negative muons in the target materials is between 100 and 200 mμsec, and since no counts were accepted for the first 400 mμsec, the muon background from the target walls was low. The peak and valley gated electrons were counted in an electron telescope consisting of two counters placed at 90° to the incident muon beam. The ratio of the number of events for the cases of the target filled with liquid helium and the target empty was 3.56. The observed ratio of peak to valley counts was 1.03 ± 0.02. After corrections for background, finite gate width, and solid angle are made, the asymmetry coefficient for μ^- mesons decaying in liquid helium is 0.024 ± 0.01. For comparison the observed ratio of peak to valley counts for μ^- mesons stopping in carbon was 1.09 ± 0.013 and the asymmetry coefficient is 0.054 ± 0.006. The errors indicated are standard deviations due to counting statistics.

* Research supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission with Nevis Laboratories and by the Air Force Office of Scientific Research with Yale University.
[1] Garwin, Lederman, and Weinrich, Phys. Rev. **105**, 1415 (1957).

X5. Search for $He^+\mu^-$ Atom.* D. MCCOLM AND K. ZIOCK, *Yale University*, AND V. W. HUGHES, S. PENMAN, AND R. PREPOST, *Columbia University.*—A search has been made for the formation of the atom[1] $He^+\mu^-$ when negative muons are stopped in liquid helium, using the apparatus described in the previous abstract. In a magnetic field perpendicular to the muon beam direction, the total magnetic moment of the $F=1$, $M=\pm 1$ (M = magnetic quantum number with respect to muon beam direction) states of $He^+\mu^-$ will precess with a frequency of 1.4 Mc/sec-gauss. In a magnetic field of 3.9 gauss, a search for this precession was made by observation of the time distribution of the decay electrons with time-to-pulse height and pulse height analyzer circuits.[2] The data were Fourier analyzed with the aid of an IBM 650 computer. No precession signal was observed, whereas a precession amplitude which was 2% of the total counting rate would have been detected.

* Research supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission with Nevis Laboratories and by the Air Force Office of Scientific Research with Yale University.
[1] V. W. Hughes and S. Penman, Bull. Am. Phys. Soc. Ser. II, **4**, 80 (1959).
[2] R. A. Swanson, Phys. Rev. **112**, 580 (1958).

X6. Atomic Processes for Mu-Mesic Helium.* V. W. HUGHES, D. MCCOLM, AND K. ZIOCK, *Yale University*, AND S. PENMAN AND R. PREPOST, *Columbia University.*—Many atomic processes involving mu-mesic helium must be considered for the understanding of the experiments reported in the preceding two abstracts on the stopping of μ mesons in liquid helium. The primary experimental results are: (1) the low polarization of μ mesons decaying in liquid helium, and (2) the absence of the polarized atom $He^+\mu^-$. The second result is understandable because of the very high probability of an Auger transition and because of the low binding energy of an electron to $He^{++}\mu^-$ as compared to the binding energy of an electron in He. The primary point of interest for the first result is the relatively low polarization of μ^- in liquid helium as compared with other targets with zero nuclear spin. This observation proves that a Z-independent depolarization mechanism[1] involving only the spin-orbit interaction and radiative

transitions is insufficient for an understanding of the depolarization. Effects dependent on Z which may influence the depolarization include: (1) atomic state into which μ^- is captured, (2) Auger transitions, and (3) collisions causing transitions between atomic states.[2]

* Research supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission with Nevis Laboratories and by the Air Force Office of Scientific Research with Yale University.
[1] M. E. Rose, Bull. Am. Phys. Soc. Ser. II, **4**, 80 (1959).
[2] N. A. Krall and E. Gerjuoy, Phys. Rev. Letters **3**, 142 (1959).

X7. Proton-Proton Triple Scattering at 210 Mev.* A. ENGLAND, W. GIBSON, E. HEER, AND T. TINLOT, *University of Rochester*.—As part of a program to determine the p-p scattering matrix at 210 Mev, we have measured the parameter A in a triple scattering experiment. The 90% transversely polarized proton beam of the Rochester Synchrocyclotron was bent in the plane containing the polarization vector by a magnetic field through an angle of $\Omega=28.8°$. The polarization vector was thus rotated by $\chi=63.5°$. This beam, partially longitudinally polarized, was scattered from liquid hydrogen in a plane containing the transverse component of the polarization vector. The transverse component of the polarization in the scattering plane, ϵ_A/ϵ_c, was measured using the polarimeter described earlier.[1] Using the values for R obtained earlier,[1] the parameter A was calculated from $A=-(R\cos\chi+\epsilon_A/\epsilon_c)/\sin\chi$.

θ cm	39°	40	50°	60°	70°	80°
ϵ_A/ϵ_c	+0.437	+0.339	+0.168	+0.049	−0.048	−0.062
$\Delta\epsilon_R/\epsilon_c$	0.033	0.026	0.028	0.034	0.047	0.092
A	−0.386	−0.313	−0.169	−0.086	−0.019	−0.052
ΔA	0.038	0.030	0.032	0.038	0.054	0.105

We are continuing the experiment in order to reduce the statistical uncertainties.

* Supported in part by the U. S. Atomic Energy Commission.
[1] E. Heer *et al.* and J. Tinlot *et al.*, Bull. Am. Phys. Soc. Ser. II, **4**, 252 (1959).

X8. Electron Proton Scattering at 1 Bev.* ROBERT R. WILSON, *Cornell University*.—The scattering of electrons by protons has been studied using the Cornell strong focusing synchrotron. A thin target of CH_2 is placed in a straight section where the electron beam is caused to make many traversals of the target at the peak of the acceleration cycle. Scattered electrons or recoil protons are focused on a defining scintillation counter by a single quadrupole lens. Electrons are identified by a total absorption Čerenkov counter, protons by pulse height in a scintillation counter. Elastically scattered or recoil particles show up as sharp peaks occurring when the magnet current corresponds to the appropriate momentum. The product of the number of electrons traversing the target and its equivalent thickness is measured by an absolute determination of bremsstrahlung radiation. Measurements at 67.8° and at energies between 600 and 1000 Mev give values of the form factor of the proton decreasing smoothly from 0.54 ± 0.03 at a momentum transfer, q^2, of $3f^{-2}$ to 0.061 ± 0.009 at a q^2 of $19f^{-2}$ consistent with an exponential radial distribution of charge with rms radius of $0.79\pm0.03f$. Measurements are being extended to other angles, higher values of q^2, and to deuterium.

* Work supported by the Office of Naval Research and the U. S. Atomic Energy Commission.

SATURDAY AFTERNOON AT 1:30

Statler-Hilton Penn Top South

(T. H. KRUSE presiding)

Nuclear Reactions and Energy Levels IV

XA1. Coulomb Excitation of Li^7, F^{19}, and Na^{23} by Ne^{20} Ions. P. H. STELSON AND F. K. MCGOWAN, *Oak Ridge National Laboratory*.—Ne^{20} ions of 9 to 11 Mev obtained by the acceleration of doubly-charge ions in the ORNL 5.5 Mv Van de Graaff have been used to study Coulomb excitation in light nuclei. Excitation of the following states has been observed: Li^7, 478 kev; F^{19}, 110 and 197 kev; Na^{23}, 440 kev. The best values for the reduced electromagnetic transition probabilities are as follows: 478-kev state of Li^7, $B(E2)_{ex}(cm^4)=7.3\times10^{-52}\pm20\%$; 110-kev state of F^{19}, $B(E1)_{ex}(cm^2)=6.3\times10^{-30}\pm25\%$; 197-kev state of F^{19}, $B(E2)_{ex}(cm^4)=5.0\times10^{-51}\pm20\%$; 440-kev state of Na^{23}, $B(E2)_{ex}(cm^4)=1.1\times10^{-50}\pm20\%$. The above value for the $B(E2)_{ex}$ for the 478-kev state in Li^7 gives the result that the partial half-life for the $E2$ decay is 1.5×10^{-9} sec. Taking the half-life for $M1$ decay as 8×10^{-14} sec one obtains the very small value of 5×10^{-5} for the ratio $E2/M1$.

XA2. Spin Determinations from the (n,n') Reaction for Even-Even Nuclei, $A=48$-68.* D. M. VAN PATTER, *Bartol Research Foundation*.—Hauser-Feshbach calculations for the (n,n') reaction have been carried out for Ti^{48}, Cr^{52}, Fe^{56}, Ni^{58}, Ni^{60}, and $Zn^{64,66,68}$ for $E_n\leq3$ Mev, using the diffuse surface potential of Emmerich.[1] The theoretical cross sections were compared to the results of a $(n,n'\gamma)$ survey for these nuclei,[2] with the objective of examining the reliability of spin determinations for the second and third levels by this method. It is found that both the experimental cross sections and cross-section ratios (σ_2/σ_1 and σ_3/σ_1) are systematically lower than the theoretical predictions, up to a factor of two. The use of less absorption in this potential, particularly for $E_n\leq1$ Mev, might well diminish these discrepancies. Nevertheless, it is still possible to differentiate unambiguously between spin possibilities of 2 and 4 for the second or third levels of these nuclei. From these comparisons, the best choice of spin for the following levels is found to be: Ti^{48} 2.42 Mev (2); Ni^{58} 2.46 Mev (4); Ni^{60} 2.29 Mev (0, 1).

* Assisted by the U. S. Atomic Energy Commission.
[1] W. S. Emmerich, Westinghouse Research Report 60-94511-6-R19 (April, 1958).
[2] Malik, Rothman, and Van Patter, Bull. Am. Phys. Soc. Ser. II, **4**, 258 (1959).

XA3. Energy and Angular Distribution of Protons from (α,p) Reactions.* L. W. SWENSON AND N. CINDRO,† *Massachusetts Institute of Technology*.—The results of proton energy spectra measurements at several angles from 30.5 Mev alpha particle induced reactions on Al^{27}, V^{51}, As^{75}, Nb^{93}, Rh^{103}, In^{115}, and Ta^{181} were analyzed using the statistical model. The differential cross section and level density are so obtained. The spectra are characteristic of compound nuclear process with indication of direct reaction contribution at forward angles and low excitation. The nuclear temperature $1/T=d(ln\rho)/dE$ at two excitation energies and the parameter α of $\rho\sim\exp[(aE)^{\frac{1}{2}}]$ of the residual nuclei determined from the 150° data are presented in the table.

Nucleus	W^{184}	Sn^{118}	Pd^{106}	Mo^{96}	Se^{78}	Ni^{62}	Cr^{54}	Si^{30}
T (11 Mev)	1.26	1.7	2.0	1.9	1.9	1.8	2.0	2.3
T (5 Mev)	0.8	1.8	1.0	1.1	1.15	1.2	1.35	1.4
α	26.0	15.6	12.8	11.2	15.5	11.2	11.2	7.2

The magic nucleus Sn^{118} shows higher temperature at low excitation. The spectra are adequately described by the above form of ρ at 150°. This provides a frame of reference from which the importance of the direct reaction contribution may

be evaluated. Eisberg *et al* find much lower values of α at 40 Mev.

* This work is supported in part by funds provided by the U. S. Atomic Energy Commission, the Office of Naval Research and the Air Force Office of Scientific Research.
† Acknowledgment is made to the U. S. Air Force for use of the Laboratory for Nuclear Science Data Center which was established with funds provided by the Air Force Office of Scientific Research.

XA4. High-Resolution Studies of (d,p) and (d,t) Reactions in the Isotopes of Lead and Neighboring Nuclei.* B. L. COHEN, R. E. PRICE, AND S. MAYO, *University of Pittsburgh.*—Energy distributions of protons and tritons from (d,p) and (d,t) reactions on the isotopes of Pb and neighboring nuclei were measured at several angles with ~80 kev resolution. From $Pb^{208}(d,t)Pb^{207}$, where all reduced widths are single particle, the dependence of cross section on l_n and Q value was determined, and these results were used to determine reduced widths for other reactions. The levels excited by $Pb^{207}(d,t)Pb^{206}$ are exactly as predicted by True and Ford,[1] and the reduced widths agree well with their calculations. The principal features of $Pb^{206}(d,t)Pb^{205}$ and $Bi^{209}(d,t)Bi^{208}$ can also be explained. The high energy proton spectrum from $Pb^{206}(d,p)Pb^{207}$ agrees with the predictions of True and Ford;[1] a new level was found at 1.96 Mev but it is not the missing $(h_{9/2})^{-1}$ state which must be almost degenerate with another state. The low energy proton spectra from all isotopes is featured by three very strong peaks at $Q \simeq +0.2$, -0.3, and -0.8 Mev; these would appear to be the $s_{1/2}$, $d_{3/2}$ and $d_{5/2}$ states, but angular distributions do not support these assignments. The angular distribution from $Pb^{206}(d,p)Pb^{207}$ (G. S.) exhibits sharp structure and is not forward peaked as has been experimentally reported and theoretically predicted.

* Work done in the Radiation Laboratory and assisted by the National Science Foundation and by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] W. W. True and K. W. Ford, Phys. Rev. 109, 1675 (1958).

XA5. (d,t) Reactions on Nuclei Near $A=60$. I.* B. ZEIDMAN, B. J. RAZ,† AND J. L. YNTEMA, *Argonne National Laboratory.*—Energy spectra of tritons from the (d,t) reactions on a number of nuclei with masses between $A=51$ and $A=68$ have been obtained at a deuteron energy of 21.5 Mev. The experiment was performed in the 60-in. scattering chamber with a double NaI(Tl) crystal system for particle identification. The energy spectra indicate that for all nuclei except Fe^{57} and Zn^{67} the reaction proceeds mostly to states near the ground state of the final nucleus. The absolute differential cross sections were obtained at 27° (lab.) and angular distributions of the various triton groups were taken over a range of angles from 11° to 70°. The angular distributions exhibit an oscillatory behavior and have been fitted with Butler's theory for neutron pickup. The Butler formalism and empirically determined constants have been used to obtain reduced widths.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Now at State University, College on Long Island, Oyster Bay, New York.

XA6. (d,t) Reactions on Nuclei Near $A=60$. II.* B. J. RAZ,† J. L. YNTEMA, AND B. ZEIDMAN, *Argonne National Laboratory.*—The angular distributions of the triton groups observed in the (d,t) reaction on V^{51} and Cr^{52} correspond to $l=3$ transitions. This implies that there is no admixture of a $2p_{3/2}$ neutron configuration near the closure of the $f_{7/2}$ shell. In the case of the other nuclei studied (Mn^{55}, Fe^{56}, Fe^{57}, Co^{59}, Ni^{60}, Cu^{63}, Cu^{65}, Zn^{64}, Zn^{66}, Zn^{67}, and Zn^{68}), both $l=1$ and $l=3$ transitions are observed. From the reduced widths, it is possible to make conjectures concerning the ground state configurations of nuclei in this region and to compare them with shell-model predictions; e.g., in the case of Fe^{56} the present results seem to indicate an admixture of approximately 57% $(f_{7/2})^2$ and 43% $(p_{3/2})^2$. In the case of both Fe^{57} and Zn^{67} there are indications that the ground state configurations are rather complex.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Now at State University, College on Long Island, Oyster Bay, New York.

XA7. (α,t) Reactions on V, Mn, Co, and Cu^{65}.* J. L. YNTEMA, *Argonne National Laboratory.*—The triton spectra from the bombardment of V, Mn, Co, Cu^{63}, and Cu^{65}, with the 43-Mev α beam have been obtained. The tritons were detected with a double NaI(Tl) crystal. The groups to the low-lying levels of the final nuclei were clearly resolved. Angular distributions over the range from 7° to about 30° were obtained. The cross section is peaked sharply in the forward direction and in several cases exhibits an oscillatory behavior. The transition to the ground state of Fe^{56} can be fitted with $J_l(QR)$, where $R=7$ fermis, Q the momentum transfer vector, and $l=3$ and the transition to the 2.08-Mev level with $l=1$. The transition to the ground state of Zn^{68} can be fitted with $l=1$, while for the transition to the ground state of Ni^{60}, $l=3$ appears to be required.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

XA8. Total Reaction Cross Sections for 21-Mev Deuterons.* T. H. BRAID, J. L. YNTEMA, AND B. ZEIDMAN, *Argonne National Laboratory.*—The 21.6-Mev deuteron beam of the Argonne 60-in. cyclotron has been used to measure the total reaction cross section for Au, Ag, and Zn. The beam was scattered by a 0.0001-in. Au foil in the center of the 60-in. scattering chamber. The monitor was set up at $-15°$ to the beam and the transmission equipment at $+15°$ to the beam. The deuterons incident on the transmission equipment passed in succession through a NaI(Tl) crystal 0.010 in. thick (mounted in an airtight box with permalloy entrance and exit windows) and an absorber foil, and were stopped in a NaI(Tl) crystal 0.05 in. thick. The absorber foils were mounted in a disk which could be rotated by remote control. The experiment was performed by making alternate runs with and without absorbers. The signal from the first detector was displayed on a 100-channel analyzer which was gated in anticoincidence with the elastic deuteron peak. Even with no absorber there is a substantial anticoincidence counting rate which may be due to reactions in the second crystal. To maintain similar conditions with and without absorbers it appeared necessary to suitably degrade the incident energy for the runs without the absorber.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

SATURDAY AFTERNOON AT 1:30

Statler-Hilton Ivy Suite

(E. M. CONWELL presiding)

Semiconductors III

Y1. Hall Field in Cadmium Arsenide. A. S. FISCHLER, *International Business Machines Corporation Poughkeepsie.*—The Hall coefficients of the intermetallic semiconductor $CdAs_2$ have been measured on oriented single crystals. Measurements were made as a function of the angle between the applied magnetic field and the current and as a function of the mag-

netic field intensity. A finite Hall field, linear in the magnetic field H was observed when H and the current were parallel along a principal crystal axis. The observed effect showed a strong dependence on sample purity. Although allowed by macroscopic crystal symmetry (C_4) the effect cannot be explained using the Boltzmann equation with the introduction of a momentum dependent relaxation time.[1,2]

[1] Swanson (private communication).
[2] Price, I. B. M. Journal 1, 239 (1957).

Y2. Zone Refining and Crystal Growth of Peritectic Compounds.* DONALD R. MASON AND J. STANLEY COOK, *University of Michigan* (introduced by D. F. Edwards).—The purification and selective contamination of congruently melting materials has been described quantitatively using mass balance relationships. By superimposing a proper temperature distribution, dictated in part by the phase diagram of the system, and considering the rate processes accompanying solidification and crystal growth, ingots containing large crystal grains can be produced in zone refining equipment. These concepts have been extended and applied to the peritectic compound cadmium indium telluride, $CdIn_2Te_4$. Homogeneous samples have been prepared for optical and electrical characterization.

* This work was supported in part by the National Science Foundation, and in part by Project Michigan (administered by the U. S. Army Signal Corps).

Y3. Optical Properties of the Semiconducting Compound $CdIn_2Te_4$.* D. F. EDWARDS, *Willow Run Laboratories*, AND D. O'KANE, *University of Michigan*.—The optical properties were investigated of n-type $CdIn_2Te_4$[1] at room temperature for wavelengths between 1 and 37 μ. Values of the absorption coefficient and index of refraction were obtained for samples having different carrier concentrations. From a plot of α^1 and α^2 *vs* energy, there is evidence of direct and indirect transitions. Details will be given of this analysis as well as for the values of the direct and indirect transition band gaps. Values for the electron effective mass and the relaxation time are estimated from a study of the free carrier susceptibility and the Hall coefficient.

* This work was supported by Project Michigan (administered by the U. S. Signal Corps).
[1] D. H. Mason and J. S. Cook, preceding abstract.

Y4. Substitution of Group III for Group V Atoms in Bi_2Te_3 and Sb_2Te_3.* ARTHUR J. ROSENBERG AND ALAN J. STRAUSS, *Lincoln Laboratory*.—The solid solubilities of In_2Te_3 and "Tl_2Te_3" in Bi_2Te_3 and Sb_2Te_3 have been found to approach 50 mole percent. The lattice parameters of the solid solutions are slightly less than those of the host compounds. Single crystal or coarse-grained polycrystalline samples of the alloys have been prepared by the Bridgman method, and their resistivities, Hall coefficients, and thermoelectric powers have been measured at room temperature. The substitutions of the Group III elements are essentially nondoping. The major effect is a strong reduction in the hole mobility. The significance of these results will be discussed with reference to chemical bonding in the C_{33} structure type.

* The work reported in this paper was performed by Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology with the joint support of the U. S. Army, Navy, and Air Force.

Y5. Avalanche Breakdown Studies of Silicon Junctions. PAUL H. SMITH,* *Motorola Semiconductor Products Division*, AND C. J. KEVANE, *Arizona State University*.—Experimental studies of breakdown in silicon junctions show microplasma current pulses, which extend well into the low impedance avalance region. As many as thirteen distinct sets of current pulses were observed in the breakdown of one junction. The occurrence of large numbers of distinct pulse sets is associated with the distribution of microplasma breakdown voltages over a significant range. Junctions in some unusual silicon show this range to be so large that the characteristics of a single microplasma can be studied. There appears to be no spatial correlation between microplasmas having nearly the same breakdown voltage, and it is possible by sectioning to increase the voltage isolation of a low-voltage microplasma. Studies of these isolated microplasmas reveal that many types exist and permit a negative resistance model to be used which is in essential agreement with that of Rose.[1] Direct measurement of the transition probabilities to and from the conducting state[2] have been made for one of these isolated microplasmas.

* Now at General Transistor Corporation.
[1] D. J. Rose, Phys. Rev. 105, 413 (1957).
[2] K. S. Champlin, J. Appl. Phys. 30, 1039 (1959).

Y6. Thermionic Behavior of *P-N* Junctions. MELVIN CUTLER,* *General Atomic*.—Emission (or diode) theory is used for deriving the equations for the flow of carriers and electronically transported heat across a *P-N* junction. In contrast to the usual equations, these apply if there is an appreciable temperature drop in the barrier region. When expressed in terms of external potentials, they show that the usual junction equation is modified simply by having in the exponential a thermoelectric voltage in addition to the applied voltage. The thermoelectric voltage depends on the carrier concentration on the low concentration side of the barrier. The *P-N* junction equations bear a close relation to those for a thermionic diode. As expected, the *P-N* junction equations obey Onsager's relations for small signals, but not for large signals. By reducing the barrier to zero, a rough derivation is obtained for equations for flow in a nearly homogeneous semiconductor which agrees with those appearing in the literature. It is possible to show in a simple manner that in the small signal case a junction provides no advantage over homogeneous semiconductors as a thermoelectric device.

* John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.

Y7. Li-B Pairing in Si by Ion Drift in *np* Junctions.* E. M. PELL, *General Electric Research Laboratory*.—The Li-B ion pairing reaction[1] has been investigated in Si by measuring its effect on the diffusion constant of Li, using the method of ion drift in an *np* junction.[2] The distance of closest approach, determined by the best fit of the data to the Reiss model, is about 2.6 A. The relaxation time for ion pairing was measured by the same technique at 0°C and yields a reasonable value for the capture radius.

* Supported by the U. S. Air Force Cambridge Research Center.
[1] Reiss, Fuller, and Morin, Bell System Tech. J. 35, 535 (1956).
[2] E. M. Pell, Philadelphia Meeting of the Electrochemical Society (May, 1959).

SATURDAY AFTERNOON AT 1:30

New Yorker Grand Ballroom

(M. B. GOTTLIEB presiding)

Plasma Physics

YA1. Theory of the Plasma Radiation.* A. ISIHARA, *Polytechnic Institute of Brooklyn.*—The radiation from a plasma gas is calculated solving Maxwell's equation together with Liouville's equation for the distribution function of charged particles. It is found that besides such radiation as the dipole radiation which is the sum of individual particle radiations, there exists a radiation which is intrinsic to a plasma gas. This radiation is determined by the time dependent solution of the reduced Liouville's equation. The properties of this radiation will be discussed.

* This research was supported by the U. S. Air Force through the Office of Scientific Research.

YA2. Langmuir Probe Measurements in a Supersonic Plasma Jet.* L. TALBOT, *University of California, Berkeley.*—Measurements have been made by means of a stagnation point Langmuir probe of the ion concentration and electron temperature in a supersonic low density plasma jet flow. Preliminary results yield an ion concentration of ~0.1% in the uniform core of the flow, with an electron temperature of 10 000°K. The electron temperature measurements indicate a possible Ramsauer depletion of the high-energy end of the electron distribution, making it non-Maxwellian. Heat transfer measurements at the stagnation point show a variation with potential in accordance with theoretical predictions.

* This work was supported in part by the Office of Scientific Research and by the Office of Naval Research.

YA3. Equilibrium Properties of a Partially Ionized Plasma.* GILDA MAKI HARRIS AND JOHN TRULIO, *Lawrence Radiation Laboratory, Livermore.*—A model for a partially ionized, partially dissociated plasma has been formulated using known concepts to describe bound and free electron states, internal degrees of freedom, and coulomb interactions. It has been applied to a system of particles arising from the hydrogen molecule. The Coulomb interaction is treated in the Debye approximation, modified by a distance of closest approach between ions and free electrons depending on the kinetic energy of the electrons. Vibration and rotation are treated in the harmonic oscillator and rigid rotor approximation with a finite number of states. A volume dependence of the electronic energy eigenvalues of each particle is included. A given state is bound until its energy increases to zero. By a minimization of the total free energy the equilibrium composition as a function of temperature and volume is obtained, thermodynamic quantities are calculated, and regions where incomplete ionization and dissociation are important are delineated. Also, the relative contributions of Coulomb interactions, quantum behavior of electrons, internal motion, and translation to the energy can be determined.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

YA4. Axial Magnetic Field Charged Particle Trajectory Study. Circular Current Loop Field Forbidden Zones and First-Order Relativistic Trajectories. MALCOLM A. MACLEOD, *Boston College and Giannini Plasmadyne Corporation,* AND RALPH W. WANIEK, *Giannini Plasmadyne Corporation.*—In designing magnetic fields for use in such work as plasma confinement, radiation production, and beam compression it is of value to be able to obtain rapidly a feel for the behavior of a given field configuration. The forbidden zones of Störmer give just such important qualitative information on the trajectories of charged particles in electromagnetic fields. The zone shapes have been worked out and a number of first-order relativistic trajectories have been numerically calculated for one of the simplest cases, the circular current loop magnetic field. The influence of injection conditions on the zone shapes and the influence of the zone shapes jointly with the injection conditions on some of the pertinent system parameters (such as beam compression, defocusing, and acceptance angles) will be discussed. The accuracy of the calculated trajectories will be estimated and the regions of applicability of the study delineated.

YA5. Diffusion Equation for Particles Trapped in Magnetic Fields.* M. WALT, *Lockheed Missiles and Space Research Laboratory,* AND WILLIAM M. MACDONALD, *University of Maryland.*—Adiabatic invariance of the magnetic moment of charged particles in a nonuniform magnetic field leads to distributions of particles "trapped" in certain fields. Examples occur in the thermonuclear "mirror machine" and in the radiation belts around the earth. Coulomb collisions among the particles or with the atmosphere produce changes in the magnetic moments and a leakage of particles. A method of treating the effect of collisions in the mirror machine[1] was generalized and applied to the radiation belts by Wentworth, MacDonald, and Singer. Another approach was developed by J. M. Welch and applied to the radiation belts. In order to clarify the relationship of these calculations and the implicit approximations a more complete and consistent derivation of a diffusion equation has been made. The approach is a generalization of the Fokker-Planck equation to discuss the temporal evaluation of a particle distribution through quasi-equilibrium distributions in velocity and space. The approximations contained in other calculations of lifetimes will be pointed out, and the effect upon lifetimes discussed.

* Supported in part by the Office of Naval Research.

[1] Judd, MacDonald, and Rosenbluth, University of California Radiation Laboratory Report UCRL-2931 and *Proceedings of the Second United Nations Conference on the Peaceful Uses of Atomic Energy, 1958* (United Nations, 1958), Vol. 32, p. 248.

YA6. Experiments on Supersonic Plasma Flow along Magnetic Fields. III.* DAVID M. WETSTONE, *New York University.*—Experimental results are presented, via time-integrated photographs, of Cu plasmoid flow along curved magnetic fields of 1.4 and 2.8 weber/m². The ability of the plasmoid to follow the field lines improved with decrease in density, as the single particle model was more closely approached, and, in some instances, improved with increase of field strength. Previously reported results[1] noted that plasmoid axial velocities approached 5.5 cm/μsec with an upper bound ion temperature of 120 ev. This work is a logical extension of that reported by Finkelstein *et al.*[2] and concludes the project first described by Wetstone *et al.*[3]

* Work performed under the auspice of the U. S. Atomic Energy Commission.

[1] D. M. Wetstone, Division of Plasma Physics, Monterey, California (December 3–5, 1959).

[2] Finkelstein, Sawyer, and Stratton, Phys. Fluids 1, 188 (1958).

[3] Wetstone, Finkelstein, Ehrlich, and Livingston, Bull. Am. Phys. Soc. Ser. II 4, 41 (1959).

YA7. Magnetohydrodynamic Channel Flows under Impulsive Pressure.* J. T. YEN AND C. C. CHANG, *University of Minnesota.*—Unsteady magnetohydrodynamic channel flows

with impulsive pressure gradients (representable by step or delta functions) are investigated herein. The channel walls are taken to be perfectly conducting. The "relaxation-time" for the velocity field, the induced magnetic field as well as the electromagnetic body forces and stresses are found and discussed. Detailed profiles are plotted for the fluid whose magnetic Prandtl number χ is equal to unity.

* This work is sponsored by Applied Mathematics Branch, Aeronautical Research Laboratory, Wright Air Development Center.

YA8. Injection and Trapping of High-Current Electrons.* R. C. JOPSON, W. A. S. LAMB, AND R. E. WRIGHT, *Lawrence Radiation Laboratory, Livermore.*—Experiments have been performed utilizing the electron beams of 600 kev and 30 amp in connection with the development of the Astron[1] thermonuclear device in which beams of electrons are trapped in a uniform solenoid and their decay measured as a function of gas pressure and other operating parameters. Estimates of the total number of electrons trapped are approximately 10^{12} and they are contained for the order of one sec.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] N. C. Christofilos, *Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy* (United Nations, 1958), Vol. 32, p. 279.

YA9. Injection and Trapping of High-Current Electron Beams.* N. C. CHRISTOFILOS, *Lawrence Radiation Laboratory, Livermore.*—Irreversible injection and trapping of high-current electron beams rotating in a magnetic potential well has been investigated. The trapping region is a long cylinder where an axial magnetic field has been established. The potential well is created by the two mirror coils placed at each end of the trapping region. The electrons are injected at the "top" of the mirror field. The irreversible trapping can be achieved by allowing the electrons to slide downhill in the potential well while simultaneously losing energy to a suitable arrangement of passive circuits. The electrons after injection from a cylindrical layer or bunch as they rotate in the guiding magnetic field. As they slide downhill entering the potential well they pass near resistive loops. The magnetic field of the electron bunch generates currents in the resistive loops, resulting in energy loss, which, in turn, absorbs axial kinetic energy from the electron bunch. Hence, the bunch arrives at the bottom of the potential well with very small axial momentum and the electrons are thus trapped. Calculations of the parameters of the resistive loops and the decelerating force will be presented. Application of this injection method in the Astron device will be discussed.

* Work done under the auspices of the U. S. Atomic Energy Commission.

YA10. Oscillations and Current Characteristics of the Tantalum Plasma Diode.* RAYMOND FOX AND WILLIAM GUST, *Lawrence Radiation Laboratory, Livermore.*—The characteristics of a plasma diode which had a tantalum cathode and a cesium-on-nickel anode were investigated. The cesium pressure in the tube was controlled by varying the temperature of the tube wall. A guard ring geometry and a double guard ring geometry was used. Cathode temperatures from 1800°K to 2400°K, cesium pressures from 2×10^{-3} mm to 2 mm, and a number of anode temperatures were investigated. The output current as a function of voltage was characterized by a fairly flat region from zero volts up to a "break-off-voltage." The "break-off-voltage" could be varied up to a maximum of 2.7 v. The current decreased rapidly for output voltages greater than the "break-off-voltage." The oscillations which were observed could be synchronized by an oscilloscope. A series of photographs were taken of the wave forms of the oscillations as a function of the tube parameters. The oscillations only occurred for output voltages less than the "break-off-voltage." The amplitude of the oscillations was as great as two v. The period of the oscillations was comparable to the transit time of an ion across the diode. The experimental results and their interpretation will be presented.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

YA11. Thermoelectric Conversion in Cesium Cells.* WERNER B. TEUTSCH, *General Dynamics Corporation.*—Experiments have been carried out to study the conversion of heat to electricity in diode configurations, with varying amounts of cesium vapor, presumably partly ionized, between the cathode and anode. Lewis and Reitz have analyzed this situation in terms of the equilibrium transport properties of the cesium plasma. Their analysis holds for high pressures of cesium vapor and/or large cathode-anode spacing, i.e., for spacings very much larger than the mean free path of thermal electrons. In the usual case, however, the converse condition holds, and a better approximation is to assume that all electrons which leave the cathode enter the anode, provided they have sufficient energy to overcome the appropriate potential barriers. It should be noted that, because of the energy-dependence of the Coulomb cross section, a large fraction of the electrons (*viz.*, those with more than average energy) will not be scattered, even when the characteristic spacing and the mean free path are comparable. The model of a diode with no space charge provides an excellent starting point for the analysis of a cesium cell.

* Supported in part by the Rocky Mountain-Pacific Nuclear Research Group.

SATURDAY AFTERNOON AT 1:30

New Yorker Boston Room

(JULIAN SCHWINGER presiding)

Theoretical Physics VII: Field Theory

Z1. Finite Theory of Electrons. OTTO BERGMANN, *RIAS.*—A relativistic action principle is proposed, which results in a finite theory of electrons. Conservation laws of charge, energy, and momentum are derived, and the transformation properties of these conserved quantities are the same as in the usual theory. Particles, whose masses and charges are given *a priori*, are introduced as point singularities, and their world lines follow from Lorentz' equation of motion without, however, any self-force. The field created by a particle is the same as in the usual theory, but this field does not carry energy and momentum of its own. Integrable densities of energy and momentum are obtained whenever the fields of two or more particles, but not their world lines, overlap. The energy of the field, and therefore the total energy, is not positive definite. Although the fundamental equations do not differ greatly from those of the usual theory, such a reformulation of the electromagnetic theory has far-reaching consequences; but definite conclusions must wait on a quantum mechanical formulation.

Some of the startling consequences, which are studied in greater detail in a paper in the *Acta Physica Austriaca*, will be outlined.

Z2. Baryon Doublets and Neutrino Doublets. E. J. SCHREMP, *U. S. Naval Research Laboratory*.—A previously suggested parallelism[1] between baryon doublets and "neutrino doublets" is here further explored. Among the involutory transformations which leave invariant the 8-component wave equations of I, there exist two, namely $\psi_\pm \rightarrow i\psi_\pm e$ and $\psi_\pm \rightarrow {}^*i\psi_\pm e$, where $e^2=-e_0$, whose eigenfunctions satisfactorily describe baryon doublets and neutrinos, respectively. The eigenvalues ± 1 of the first transformation are identifiable with hypercharge; while those of the second characterize two physically distinct kinds of "2-component neutrino," both of which might actually exist as leptonic analogs of the nucleon and cascade particle. Through this "neutrino doublet" representation, the usual "2-component neutrino" becomes describable in a more general manner which admits isospin rotations but is invariant under them. The physical difference between "neutrino doublets" and baryon doublets is here clearly seen to arise from a fundamental difference in the *symmetry properties* of their 2×4 matrix wave functions. This illustrates in detail a general principle, first advanced in I, to the effect that differences in kind among spin $\frac{1}{2}$ elementary particles arise from differences in the symmetry properties of their 2×4 matrix wave functions.

[1] E. J. Schremp, Phys. Rev. 113, 936 (1959); cited hereinafter as I.

Z3. Iteration of the *S* Matrix in Finite Terms. KURT HALLER, *New York University*.—A new perturbative iteration procedure has been developed for the case of boson scattering from a static source. The procedure involves a perturbative solution of a series of nonlinear integral equations for the S matrix, based upon a scattering formalism in which the asymptotic states need not be eigenstates of any Hermitean operator[1] (such as the unperturbed Hamiltonian). This was done to investigate the connection between the appearance of divergent S-matrix elements in field theory, and the incorrect assumption that the asymptotic scattering states are eigenstates of free field Hamiltonians. The asymptotic states were taken to be product wave functions of the pion and the physical nucleon. This theory has been applied to the case of charge-symmetric scalar bosons which, in the old theory, gives renormalizable ultraviolet divergences. The S matrix has been evaluated by this new method to the sixth order, with the following results. The iteration parameter appears naturally in its "renormalized" form; all S-matrix elements are finite and agree with the finite expressions for the same diagram obtained by renormalizing the old theory.

[1] H. Ekstein, Phys. Rev. 101, 880 (1956).

Z4. Invariance Properties of the Dirac Electron Theory.* J. F. PLEBANSKI AND D. L. PURSEY, *University of California, Los Angeles* (sponsored by D. S. Saxon).—If the Dirac field operator is divided into its "left" and "right" components, and these are recombined in a new manner, then it is natural to interpret certain linear transformations of the new field components as Lorentz transformations in a fictitious four-dimensional space. Gauge transformations of the first kind of the original theory are rotations in a two-dimensional space-like subspace. The Pauli transformations (e.g., of the neutrino field) are rotations in a three-dimensional space-like subspace. The Dirac equations (but not the commutation rules) are invariant under transformations in a three-dimensional subspace with signature $(+--)$. The Dirac equations and commutation rules can be made covariant under transformations in the four-dimensional space provided suitable transformation properties are assigned to certain c-number parameters in the theory.

* Supported in part by the National Science Foundation and the Air Force Office of Scientific Research.

Z5. Form Invariance in Quantum Electrodynamics.* D. L. PURSEY AND J. F. PLEBANSKI, *University of California, Los Angeles* (sponsored by D. S. Saxon).—The principle of form invariance asserts that if a group of unitary transformations of a theory is equivalent to a group of transformations of c-number parameters, the predictions of the theory depend on the parameters only through quantities invariant under the group. This principle cannot be directly applied to the full four-dimensional group of transformations of the Dirac electron theory described in the preceding abstract, since not all of these transformations are unitary. The possibility of extending the form invariance principle to this theory will be discussed.

* Supported in part by the National Science Foundation and the Air Force Office of Scientific Research.

Z6. Effect of Soft Photons on a Renormalization Theorem.* A. SHAW AND E. L. LOMON, *McGill University*.—The method of separation of hard and soft photon effects, previously discussed,[1] has been applied to sum the matrix elements for the creation of a pair together with an arbitrary number of soft photons of total energy ΔE. The sum over real intermediate pair states used in Källèn's "minorant" for the quantity $\pi(p^2)$ at high energies[2] can then be extended to include states with soft photons. The new sum in the high energy limit is, apart from the errors due to separation, $\pi^0(p^2)N_\epsilon{}^A(1-L_\epsilon)^{-2}\times(\Delta E/\gamma\epsilon)^{\alpha c}\Gamma^{-1}(1+\alpha c)$ where ϵ is a lower cutoff in N and L and an upper cutoff for the virtual photons in the soft photon factor. $C=(4/\pi)[\ln(2q_0/m)-(1/2)]$, p the four momentum of the pair, and q that of one electron in the c.m. system. This expression vanishes rapidly as $-p^2\rightarrow\infty$. The implications of this with respect to the consistency of finite renormalization constants in quantum electrodynamics will be discussed.

* Supported in part by a National Research Council (Canada) Research Grant.

[1] E. Lomon, Phys. Rev. 113, 726 (1959); Nuclear Phys. 1, 101 (1956).
[2] G. Källèn, *Handbuch der Physik* (Springer-Verlag, Berlin, 1958), Vol. V, Part 1, pp. 358–363.

Z7. Soluble Model in Field Theory.* E. KAZES, *Pennsylvania State University*.—The Lee model has been modified by giving the V particle a more complicated structure without modyifying the N, θ particles. For a Hamiltonian having $\psi_1\rightleftarrows\psi_2+\phi_2$, $\psi_1\rightleftarrows\psi_3+\phi_3$, $\psi_3\rightleftarrows\psi_4+\phi_4$, etc, as basic processes the scattering of ϕ_2 from ψ_2 or any final state resulting from such interaction can be calculated exactly. The same limitation that applies to the cut-off size in the Lee model is also reproduced here. The calculation has also been performed using dispersion relations and is in agreement with direct calculation. The Hamiltonian lends itself to the study of unstable particle and bound state production, which reveals the limitations imposed in the customary separation of the production and the decay of unstable particles. The production of bound states has been calculated using the Nishijima-Zimermann formalism and yields results identical to those obtained by direct calculation.

* Supported in part by the U. S. Atomic Energy Commission.

Z8. Presence of $\tilde{\delta}'(n^2)$ in the Photon Spectral Function.* HERBERT M. FRIED, *University of California, Los Angeles*.—Following a remark of Yennie,[1] it may be shown that in the usual formulation of quantum electrodynamics, where the photon and fermion current operators satisfy the equation $\Box A_\mu=J_\mu$, the spectral function representing the commutator of two photon fields contains a term proportional to $\tilde{\delta}'(n^2)$. This may be demonstrated by a simple argument, and more

rigorously by an explicit integration of the commutator differential equation, using the equal-times commutation relations as initial conditions (but not assuming any relation between matrix elements of the photon operators and their asymptotic values). This term appears only in the gauge-variant portion of the commutator, and hence cannot contribute to any physical process; however, its existence is incompatible with a sum-over-states derivation of the spectral function. The coefficient of $\delta'(n^2)$ is proportional to $(1-Z_3)$, indicating that it cannot be removed by the normal regularization procedure. The alternate formulation of electrodynamics developed by Källén[2] is free from this difficulty and thus appears to be, conceptually, the more proper formalism.

* This work supported in part by the National Science Foundation.
[1] D. R. Yennie (private communication).
[2] G. Källèn, Helv. Phys. Acta **24**, 417 (1952).

Z9. On Analyticity of Vacuum Expectation Values of n-Fold Products and Fully Retarded Commutators.* DANIEL KLEITMAN, *Harvard University.*—The procedure described by Källén and Wightman for determining the regions of analyticity of vacuum-expectation values of products of n-local scalar fields, and of retarded commutators of such fields, involves three steps. These are: determination of the boundaries of the extended tubes in terms of scalar products of the vector arguments; extension of analyticity from the extended tubes to the union of permuted extended tubes; and computation of the holomorphy envelope of that union. However, the second step listed in the foregoing is only clearly justified if every point in the intersection of each pair of permuted extended tubes is connected to a real point by a continuous path lying entirely in that intersection. We show that this condition is satisfied by the various intersections of permuted extended tubes for three point functions. As a consequence, the procedure actually employed by Källén and Wightman is seen to be justified. Extension of that procedure to treat four and five point functions requires that the analogous condition be satisfied by the intersections of permuted extended tubes corresponding to such functions. The question of whether or not such conditions are indeed satisfied will be discussed.

* Supported in part by the Air Force Office of Scientific Research.

Z10. Spin and Statistics with an Indefinite Metric.* RICHARD SPITZER, *Purdue University.*—The quantization of spin-0 fields according to Fermi-Dirac statistics and spin-$\frac{1}{2}$ fields according to Bose-Einstein statistics has been formulated, following a method of Pauli,[1] with an indefinite metric in the Hilbert space of quantum mechanical states. The free-field theory is shown to be invariant under a symmetry operation induced by the metric operator. The requirement that the latter commute with the interaction Hamiltonian leads to conservation of the sign of the norm of the states and to a unitary S matrix. The difficulties that are usually encountered in formulating a field theory with an indefinite metric are thus presumably avoided. The symmetry operation defines a multiplicative quantum number that distinguishes only particles, but not antiparticles, from quanta that obey normal statistics. The corresponding selection rules cannot therefore account for strange-particle phenomena if nucleons and pions are considered to obey normal statistics.

* Supported in part by Air Force Office of Scientific Research.
[1] W. Pauli, Progr. Theoret. Phys. (Kyoto) **5**, 526 (1950).

Z11. Fundamental Difference between Schrödinger and Interaction State Vectors.* F. J. BELINFANTE, *Purdue University.*—The T^{00} component of the symmetric energy density tensor for gauge-independent quantum electrodynamics [Phys. Rev. **84**, 541, 648 (1951)] is the sum of a free-field term $(\mathcal{E}_\perp^2+\mathcal{B}^2)/8\pi+Re\{\psi^\dagger(mc^2\beta-ihc\boldsymbol{\alpha}\cdot\boldsymbol{\nabla})\psi\}$ and an interaction term $W^{00}\equiv(\mathbf{E}_{II}^2+2\mathbf{E}_{II}\cdot\mathcal{E}_\perp)/8\pi-\mathbf{j}\cdot\mathcal{A}_\perp$. In the Heisenberg picture, one finds (a) $\int\int d^3\mathbf{x}d^3\mathbf{x}'\mathbf{b}\cdot\mathbf{x}'[T^{00}(\mathbf{x});\ T^{00}(\mathbf{x}')]=\frac{1}{2}ihc\times\int d^3\mathbf{x}\delta T^{00}(\mathbf{x})$, and (b) $\int\int d^3\mathbf{x}d^3\mathbf{x}'\mathbf{b}\cdot\mathbf{x}'[W^{00}(\mathbf{x});\ W^{00}(\mathbf{x}')]=ihc\times\int d^3\mathbf{x}\delta W^{00}(\mathbf{x})$. Here, $F+\delta F$ denotes the transformed of F after the infinitesimal Lorentz transformation $\mathbf{x}'=\mathbf{x}-\mathbf{b}ct$, $ct'=ct-\mathbf{b}\cdot\mathbf{x}$. Equation ($a$) is the form taken in Lorentz frames by the integrability condition of a Schrödinger equation $ihcd\Psi(\sigma,O)=\int d\sigma_\mu T_\nu^\mu(\mathbf{x})d\xi^\nu(\mathbf{x})\Psi(\sigma,O)$ with $d\xi^\mu(\mathbf{x})$ connecting points *with equal spatial coordinates* $\mathbf{x}$ on $\sigma(t)$ and on $\sigma(t+dt)$, while Eq. (b) is the Lorentz-frame form of the integrability condition of a Schrödinger equation $ihcd\Psi_0[\sigma]=\int d\sigma_\mu W_\nu^\mu(\mathbf{x})\times d\xi^\nu(\mathbf{x})\Psi_0[\sigma]$ for the interaction picture, with $d\xi^\mu(\mathbf{x})$ pointing here from $\sigma(t)$ to $\sigma(t+dt)$ "*perpendicularly*" ($\perp\sigma$). Thus, the factor $\frac{1}{2}$ present in (a), absent in (b), forces us to accept this difference in interpretation of these Schrödinger equations, making Ψ in the Schrödinger picture dependent upon the spatial origin O in σ, but Ψ_0 in the interaction picture independent of O.

* Supported in part by the National Science Foundation.

Z12. Reformulation of Certain Exactly Soluble Field Theories.* R. E. NORTON, *California Institute of Technology,* AND W. K. R. WATSON, *University of Southern California.*—It has been shown within the framework of certain classes of exactly soluble field theories,[1] that the elimination of the analogue of the classical "runaway solutions"[2] leads to a unique modification of the usual commutation rules. This change is directly attributable to the acausal properties of the systems in the limit of sufficiently weak "cutoffs," and takes place during the process of renormalization. Since the field operator describing the systems are now no longer canonically conjugate, it would appear desirable to find linear combinations of the old field operators which are canonical, and which could be interpreted as the physical operators in the new theory. These operators have been found and the Hamiltonian has been re-expressed in terms of them. The new equations of motion are now readily obtainable directly from the new Hamiltonian and the canonically conjugate field operators. Consequences and possible extensions of these techniques will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.
[1] R. E. Norton and W. K. R. Watson, Phys. Rev. (to be published).
[2] P. A. M. Dirac, Proc. Roy. Soc. (London) **A167**, 148 (1938).

Z13. Classical Point Electron. F. ROHRLICH, *State University of Iowa.*—The Abraham-Lorentz theory of the point electron has among others the difficulty that the momentum and the energy of the electromagnetic field carried along by the particle do not have the correct relationship (factor 4/3). This difficulty can be traced back to an incorrect definition given by Lorentz for these quantities. A covariant definition yields an energy-momentum four-vector which depends on the surface due to the singularity of the charge. The singularity can be removed by one of the known renormalization methods. The renormalized theory has the correct (Lorentz invariant) transformation properties of energy and momentum and consequently also yields a vanishing self-stress. The classical point electron is then stable without the need for Poincaré stresses in the same sense as the quantum electrodynamic point electron. In this form the theory naturally presents itself as the classical limit of quantum electrodynamics.

SUPPLEMENTARY PROGRAMME

SP1. Low-Energy Nucleon-Nucleon Potentials.*† D. B. LICHTENBERG, *Michigan State University.*—Some semi-phenomenological nucleon-nucleon potentials of the form $V(r) = V_2(r) + V'(r)$ are obtained, with $V_2(r)$ being the ordinary (second order) Yukawa potential given by pseudoscalar meson theory and $V'(r)$ being purely phenomenological. The fourth-order contribution to the meson-theoretical potential is not included in $V(r)$ because there is no general agreement as to its form. The function $V'(r)$ is taken to be of the form $V'(r) = -V_0(1+\alpha S_{12})e^{-\beta r}/r$ outside a hard core of radius r_0. Here S_{12} is the tensor operator, and V_0, α, β, and r_0 are spin-dependent parameters adjusted to fit the properties of the deuteron and the low energy nucleon-nucleon scattering data. To accomplish this, the Kalos-Blatt routine[1] was used to solve Schroedinger's equation numerically on an electronic computer. Some particular sets of parameters will be given and some comments made about some of the properties of these potentials.

* Work supported in part by the National Science Foundation.
† To be given at the end of Session IA if the Chairman rules that time permits.
[1] M. H. Kalos and J. M. Blatt, University of Illinois Digital Computer Laboratory Internal Report No. 50 (1953).

SP2. Properties of $CdSnAs_2$.*† ARTHUR J. ROSENBERG AND ALAN J. STRAUSS, *Lincoln Laboratory.*—Directional freezing of a stoichiometric melt of $CdSnAs_2$ leads to a single phase material crystallizing in the chalcopyrite structure with $a = 6.084$ A and $c = 11.916$ A, $c/a = 1.957$. The resistivity and Hall coefficient are 4.2×10^{-3} Ω-cm and -2.3 cm³/coul, respectively, at room temperature and are virtually the same at 78°K. These values correspond to an electron mobility of 5600 cm²/v-sec at a carrier concentration of 2.7×10^{18} cm^{-3}. The thermoelectric power at room temperature is -54 μv/degree. Therefore, despite an extremely small grain size ($<1\mu$), the electron mobility is the highest value reported for any ternary compound, and is comparable to that of monocrystal InSb at the same carrier concentration.

* The work reported in this paper was performed by Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology with the joint support of the U. S. Army, Navy, and Air Force.
† To be called for at the end of Session Y if the Chairman rules that time permits.

SP3. On the Microwave Dielectric Dispersion and Loss in High-Permittivity Ferroelectrics.*† HOWARD DIAMOND, *The University of Michigan.*—Measurements of complex permittivity *vs* frequency have been made on several ferroelectrics from 0.5 mc to 4000 mc. Dynamic permittivity spectra of $BaTiO_3$ crystals with the polar axis aligned with, and also transverse to, the high-frequency fields show a complex dimensional resonance spectrum in the 1-mc to 20-mc frequency range. For frequencies higher than 20 mc both the parallel and transverse permittivity is reduced to about one half of that at the low frequency limit, consistent with the Devonshire theory for the clamping of single crystals. Microwave data to 4000 mc fail to reveal further dispersion. On the other hand, data on several polycrystalline ferroelectric compositions including $BaTiO_3$, $Ba_xSr_{1-x}TiO_3$, $Pb_xSr_{1-x}TiO_3$, $PbTiO_3$, and $Cd_2Nb_2O_7$ show substantial reductions in permittivities at microwave frequencies. The disparity between the single crystal and polycrystal data is ascribed directly to the effects of electrostrictive and piezoelectric interactions at grain boundaries and domain walls. The effect of such loss mechanisms on reducing the apparent permittivity at high frequencies is shown to be more pronounced the higher the permittivity of the dielectric. Data are also included on the change in incremental permittivity and loss at microwave frequencies for polycrystalline ferroelectrics under static and low-frequency biasing fields.

* Work supported jointly by the National Science Foundation and the U. S. Air Force Office of Scientific Research.
† To be called for at the end of Session S if the Chairman rules that time permits.

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Gibson, W.—X7
Girardeau, M.—A10
Glauber, R. J.—H7
Goland, A. N.—G10, G11, G12, G13
Goldberg, A.—O8
Goldberg, I.—Q9
Golden, S. A.—RA11
Goldhaber, F.—BA2
Goldhaber, S.—BA2
Goldman, D. T.—MA5
Goldman, M. V.—J13
Goodman, Charles D.—UA3
Gordon, M. M.—J9
Gossard, A. C.—WA9
Gottfried, K.—H6
Goudsmit, S. A.—TA3
Gove, H. E.—MA7
Grad, Harold—M3
Graham, R. L.—F8, F9
Green, John R.—FA8
Green, Milton—SA6
Green, R. W.—S13
Greenberg, D.—X1
Greisen, Kenneth I.—FA10
Grenier, C. G.—S8
Griem, H. R.—KA7, KA8, KA9
Gupta, S. N.—Q1
Gust, William—YA10
Guth, E.—MA5
Haberstroh, R. A.—F1
Haffner, J. W.—U3
Halbert, M. L.—J13, UA8
Hales, R. W.—KA6
Hall, R. N.—JA3
Haller, Kurt—Z3
Halsted, R. E.—T9
Hamilton, D. R.—F1, F2
Hamilton, J. H.—B7
Hammerling, P.—KA3
Hanauer, S. H.—F12
Hanna, S. S.—MA6
Hansen, N. E.—J5
Happel, R. J., Jr.—NA11
Harrington, David—O13
Harris, Gilda Maki—YA3
Harrison, Walter A.—G2
Hart, E. W.—A2
Harth, E. M.—BA6
Harvey, J. A.—I11, J7
Hatcher, C. R.—J4
Hatsukade, S.—O11
Havas, Peter—Q3
Havens, W. W., Jr.—I2, I6
Heath, R. L.—F7
Heberle, Juergen—J7
Heer, E.—X7
Heller, Wilfried—GA9
Henshaw, D. G.—C3
Hensley, Eugene B.—V7
Herman, Frank—NA5, SA9
Herman, Robert—K11
Hersh, H. N.—NA9
Hoang, T. F.—BA2
Hobbie, Russell K.—DA6
Holladay, W. G.—Q11
Holloway, G. E.—I8
Holm, G. B.—UA5
Holmes, John R.—CA2
Hoover, Martin E.—CA2
Hord, B. Leroy—KA4
Hormats, E. I.—S5
Hornback, C. E.—RA9
Horton, G. K.—K14
Hough, W. S.—N10
Hrostowski, H. J.—T1
Huberman, M.—CA6
Hughes, D. J.—DA3, E9, I5, W3
Hughes, V. W.—J2, J3, X4, X5, X6
Hultberg, S.—CA4
Hunting, C. Eugene—RA3
Huntington, H. B.—K8
Hurley, J. P.—UA11
Hutchins, D. L.—F4
Hutchison, T. S.—K5
Imamura, Tsutomu—O1
Imhof, W. L.—N4
Isihara, A.—YA1
Ittner, W. B., III—C10
Iwao, Syurei—H3, H4
Jain, A.—E9
Jain, P. L.—FA12
Janin, J.—NA1
Jastram, P. S.—F4, F5
Jobes, F. C.—UA6
John, W.—MA3
Johnson, Fred M.—R1
Johnson, G. W.—D1
Johnson, N. R.—B8
Johnson, R. G.—MA8
Jones, R. E.—C11
Jopson, R. C.—YA8
Josephson, V.—KA6
Jovanovich, J. V.—UA11
Judd, D. L.—PA2
Jupiter, C. P.—J4, J5
Kadanoff, Leo P.—C7
Kaiser, W.—T1
Kane, J.—E11
Kanter, Helmut—V5
Karplus, R.—O6
Kazes, E.—Z7
Keck, James C.—GA12
Kelly, W. H.—F11
Kelsey, C. A.—DA7
Kennedy, Anthony J.—K6
Kenney, V. P.—J12
Kerth, Leroy—BA5
Kevane, C. J.—Y5
Keyes, R. W.—T8
Khare, Harish C.—J6
Kiel, A.—WA6
Kikuchi, T.—BA6
Kinoshita, T.—O7
Kisliuk, Paul—R2
Kivel, B.—KA3
Klein, C. A.—T2
Klein, M. P.—WA8
Kleitman, Daniel—Z9
Kneckt, D. J.—N4
Koch, H. W.—J5, UA10
Kolb, A. C.—KA9
Komar, Arthur B.—Q6
Kotelchuck, D.—GA4
Kraushaar, J. J.—B6
Krisher, L.—WA12
Kruse, T. H.—UA2
Kuehner, J. A.—RA7, RA8
Kurbatov, J. D.—F6
Laitone, E. V.—KA10
Lamb, W. A. S.—YA8
Lambe, E. D.—B1
Lampert, Murray A.—SA5
Landovitz, Leon F.—Q9
Lapointe, Serge M.—N1
Laponsky, A. B.—R3
Lawson, R. D.—H5
Lax, Benjamin—T3
Lax, M.—A4
Lebowitz, J. L.—A6
LeCraw, R. C.—S7
Lederhandler, S.—G6
Lee, T. D.—TA2
Lee, Y. K.—B4
Leech, J. W.—K14
Legvold, S.—S13
Leiss, J. E.—VA1
Leitner, J.—BA6
Lenchek, A. M.—N7
Levesque, R. J. A.—DA1
Levin, F. S.—H11
Lewis, Myron R.—KA1
Lichtenberg, D. B.—Q7, SP1
Lichtman, David—GA7
Lidofsky, L. J.—RA4
Lieberman, D. S.—G4
Lignos, W.—GA6
Limentani, S.—BA4
Lippmann, Bernard A.—H13
Litherland, A. E.—MA7, RA5
Lohrmann, E.—FA11
Lombard, F. J.—MA3
Lomon, E. L.—Z6
Lomont, J. S.—U11
Lord, N. W.—WA1
Lorrain, P.—E6
Loubser, J.—WA12
Lowry, R. A.—CA9
Lubitz, C. R.—E5
Luckey, D.—VA2
Ludemann, C. A.—DA1
Łunc, Michał—HA4
Lustig, Harry—H2
Lynch, P. J.—IA7
Lynes, L. L.—KA11
Macdonald, William M.—IA1, RA2, YA5
Macklin, R. L.—E3
MacLeod, Malcolm A.—YA4
Maeda, K.—FA3
Maki, August H.—WA4
Manacher, Glenn—X3
Mandelstam, S.—O9

Mann, Lloyd G.—B2, B3
Marcus, Paul M.—K6
Marinsky, J. A.—B8
Marion, Jerry B.—DA1, AI1
Markham, J. J.—NA9
Marlow, K. W.—J10
Marsh, K. V.—I12
Marshak, R. E.—IA13, O11, Q10
Martin, D. S., Jr.—RA11
Martin, H. J.—UA5
Martin, P. C.—C7, H10
Marton, L.—V1, V2
Marzke, Robert F.—NA3
Mason, Donald R.—Y2
Mayo, S.—XA4
McCallum, G. J.—RA5
McCaulley, J. W.—N10
McClelland, W. M.—VA5
McClure, Donald S.—NA5
McColm, D.—X4, X5, X6
McCullen, J. D.—B6
McDonald, R. S.—G9
McGarry, W. I.—I8
McGowan, F. K.—XA1
McIldowie, J. E. G.—MA6
McIntyre, J. A.—UA6
McLean, E. A.—KA8
McReynolds, A. W.—DA5
McVoy, Kirk W.—VA11
Meads, R. E.—MA6
Meeron, Emmanuel—A7
Mehlhop, W. A. W.—B1
Melkanoff, M. A.—UA9
Meltzer, C.—BA6
Mendlowitz, H.—V3
Menes, M.—K7
Mesnard, G.—V8
Meyer, A.—J11
Milgram, M.—G10, G11, G12, G13
Miller, Douglas—DA6
Miller, P. D.—E3
Miller, R. H.—VA9
Minguzzi-Ranzi, A.—BA6
Miskel, John A.—B2, I12
Mitra, Dipti—H1
Mittleman, M. H.—H12
Mohling, F.—A8
Moore, E. T.—MA3
Moore, R. A.—C12
Moravcsik, Michael J.—H13, OA2
Morita, M.—X1
Moses, H. E.—U11
Moszkowski, S. A.—H14, OA1
Mott, J. E.—BA8
Motz, H. T.—MA4
Moulton, G. C.—WA5
Moulton, W. G.—GA3, WA5
Mudar, J.—V12
Mukherjee, Kalinath—G4
Murphy, J. C.—WA7
Murray, R. B.—J11
Nagamatsu, H. T.—KA5
Nakagaki, Masayuki—GA9
Nash, F.—WA3
Nefkens, B. M. K.—VA4
Nelkin, Mark—K3
Nessin, M.—UA2
Newson, H. W.—E1, E2
Nier, Alfred O.—FA4
Nikolic, Nikola—MA11
Nomura, K. C.—T4, T5
Norton, R. E.—Z12
Noyes, H. P.—O2
Nudelman, S.—V12
Ogier, W. T.—G1
Ohlsen, G.—VA6
O'Kane, D.—Y3
Okaya, A.—WA3
O'Kelley, G. D.—B8
Okubo, S.—O11
Okumura, Koji—V7
Olness, J. W.—RA6
Olsen, Leonard O.—CA7
O'Malley, Thomas F.—U6
Omohundro, R. J.—I8
O'Neill, G. K.—PA3
Orear, Jay—BA9
Osborne, L. S.—VA2
Overbeck, C. J.—L2
Pak, William L.—FA10
Palevsky, H.—DA3
Palfrey, T. R., Jr.—VA3, VA4
Pan, P. M.—S3
Pandres, Dave, Jr.—U1
Panofsky, W. K. H.—PA1
Paranjape, B. V.—SA7
Parker, G. W.—F12, F14
Parker, J. L.—RA6
Parks, Donald E.—K3
Parzen, George—J8
Patel, V.—FA3
Pattenden, N. J.—I7
Paul, David I.—S12
Pell, E. M.—Y7
Penman, S.—X4, X5, X6
Penner, S.—VA1
Percus, Jerome K.—U8, U9
Perey, F. G. J.—E6
Peterson, J. M.—I3
Peterson, Vincent Z.—VA12
Pettersson, B. G.—B7
Pevsner, A.—BA6
Phillips, G. C.—MA2
Phipps, J. A.—CA9
Piccioni, Oreste—QA4
Pickart, S. J.—S10
Piper, W. W.—T9
Pixley, R.—E11
Plebanski, J. F.—Z4, Z5
Podgor, S.—I4
Pohl, R. O.—NA8
Pollak, M.—T8
Pond, T. A.—B1
Pool, M. L.—F10
Porile, Norbert T.—UA4
Porter, C. E.—DA8
Porter, William S.—IA3
Portis, A. M.—WA9
Post, Irving G.—WA11
Pound, R. V.—W1
Powell, W. M.—BA2
Pratt, G. W., Jr.—SA1
Prepost, R.—X4, X5, X6
Price, P. J.—JA1
Price, R. E.—XA4
Priest, J. R.—MA10
Prosser, J. M.—MA3
Puff, R. D.—H10
Puppi, G.—BA6
Pursey, D. L.—Z4, Z5
Rabin, Herbert—NA3
Rainwater, James—I2, W2
Ralph, D. C.—GA6
Ramaswamy, M. K.—F4
Ramsey, N. F.—U13
Raney, W. P.—K4
Ratner, Maxwell—V13
Raz, B. J.—XA5, XA6
Read, T. A.—G4
Reagan, J. B.—E8
Reeber, Morton D.—C9
Reeves, Hubert—GA1
Regier, R. B.—I9
Reinitz, K.—K8
Reynolds, G. T.—P1
Reynolds, J. H.—D2
Reynolds, J. M.—S8
Richards, L. M.—G1
Rigert, J. A.—GA5
Rikmenspoel, R.—UA1
Roberts, L. D.—F12, F13, F14, J15
Robinson, Hugh G.—WA13
Robinson, Robert J.—T11, T12
Robinson, W. A.—CA5
Rockmore, Ronald M.—C6
Rogers, D. H.—K5
Rogers, K. C.—PA4
Rohrlich, F.—Z13
Roos, Charles E.—VA12
Rose, M. E.—IA12
Rosen, Alan—N2
Rosen, J. L.—I2
Rosenberg, Arthur J.—SP2, Y4
Rosenberg, Leonard—IA4, U6
Rosenbluth, Marshall—M4
Rosenzweig, N.—DA8
Ross, Marc—U14
Rotenberg, Manuel—H5
Roth, Laura M.—SA4
Roth, R. S.—S2, S3, S4
Rothstein, Jerome—A1
Rubin, Robert J.—A3
Rudinger, George—KA2
Ruedl, E.—CA10, CA11
Rupprecht, G.—T2
Russell, J. E.—BA3
Rustad, B. M.—I6
Sachs, A.—QA2
Sáenz, A. W.—I4
Safford, G. J.—I6
Sager, A.—T8
Sakamoto, M.—K2
Samios, Nicholas P.—VA8
Satchler, G. R.—H9, IA8
Scala, Sinclaire M.—KA12
Scarf, F. L.—Q2
Schaaf, S. A.—KA11
Schaeffer, Oliver A.—FA5
Schamp, H. W., Jr.—NA4
Schiminovich, Samuel—Q5
Schlegel, Richard—A11
Schlein, P.—BA6
Schlein, P. E.—BA4, BA7, BA8
Schofer, H. S.—S2
Schrack, R. A.—VA1
Schremp, E. J.—Z2
Schulman, James H.—NA3
Schultz, J.—K12
Schwartz, H. M.—U7
Scott, B. L.—H14

Seth, Kamal K.—E2
Setti, R. Levi—BA4, BA8
Seward, F. D.—J4, UA10
Shafer, R. E.—UA10
Shafroth, S. M.—RA1
Sharp, D.—IA5
Shaw, A.—Z6
Shaw, Gordon L.—BA3, U14
Sheer, R. E., Jr.—KA5
Sheldon, W. R.—FA7
Shenker, H.—T10
Shiffman, C. A.—C8
Shimony, Abner—A9
Shrivastava, P. K.—BA8
Sidhu, S. S.—S9
Signer, Peter—FA4
Silberberg, R.—BA2
Silver, M.—V9
Simpson, J. Arol—V1, V2
Sinclair, R. N.—K2
Singer, S. F.—N5, N6, N7, N8, N9
Sirlin, A.—A8
Skeel, W. L.—F5
Skjeggestad, O.—BA8
Slater, W. E.—BA4, BA7
Slaughter, G. G.—E10, I11
Sleator, David B.—KA1
Smakula, A.—NA2
Smith, Alan B.—E7
Smith, Paul H.—Y5
Smith, R. V.—E8
Smith, Stanley F.—Q3
Sommerfield, Charles M.—U12
Sorensen, B. H.—I9
Soshea, R. W.—R4
Spedding, F. H.—S13
Spence, R. D.—S11
Spencer, E. G.—S7
Spicer, W. E.—V6
Spinner, S.—K9
Spitzer, Richard—Z10
Spruch, Larry—IA4, U6
Steinberg, P. H.—BA4
Stelson, P. H.—XA1
Sternglass, E. J.—V4
Stewart, M. G.—B5
Stewartson, K.—HA2
Stockendal, R.—CA4
Strakna, R. E.—G14
Strauss, Alan J.—Y4, SP2
Sudarshan, E. C. G.—H4, O11, Q10, U10
Suddeth, J. A.—V2
Swann, W. F. G.—FA1
Swenson, L. W.—XA3
Symanzik, K.—TA1
Talbert, W. L., Jr.—B5
Talbot, L.—YA2
Tallan, N. M.—NA7
Tani, Itiro—HA1
Tanner, N. W.—MA6
Tarski, J.—O6
Tau, L.—VA9
Teare, J. D.—KA3
Tendam, D. J.—MA10
Teucher, M. W.—FA11
Teutsch, Werner B.—YA11
Thaddeus, P.—WA12
Theus, R. B.—MA9
Thomas, Roy—FA8
Thompson, D. O.—G5
Thomson, J. O.—F14
Thurmond, C. D.—T1
Tinlot, T.—X7
Tobocman, W.—H9
Tomboulian, D. H.—GA5
Towle, L. C.—CA9
Toxen, A. M.—C11
Trees, R. E.—CA3
Trulio, John—YA3
Tubis, Arnold—IA11
Turkot, F.—BA1
Uhlenbeck, G. E.—L1
Unterleitner, F. C.—S5
Uzan, R.—V8
Van Allen, J. A.—L3
Van Patter, D. M.—OA4, UA1, XA1
Verdery, D.—B3
Vineyard, G. H.—G10, G11, G12, G13
Vinti, John P.—A12
Wagner, M. D.—V1, V2
Walker, E. D.—X2
Walker, E. H.—N6
Walker, Edward J.—C5
Walker, R. M.—G7
Wallace, P. R.—J6
Wallis, Richard F.—K11
Walsh, Peter—U5
Walt, M.—E8, YA5
Walter, F. J.—F14, J15
Waniek, Ralph W.—YA4
Warburton, E. K.—MA8
Warnock, Robert L.—Q8
Waters, J. R.—I1
Watkins, G. D.—G8, G9
Watson, K. M.—H8
Watson, W. K. R.—Z12
Watts, T. L.—UA6
Weeks, Richard F.—K10
Wehner, G. K.—R5
Weinreich, Gabriel—SA2
Weisberg, L. R.—T7
Weiser, Kurt—SA10
Weisskopf, V. F.—TA4
Weneser, Joseph—OA3
Wentworth, R. C.—N8, N9
Wenzel, William A.—BA5
Wesley, J. P.—FA2
Wetstone, David M.—YA6
White, Harry G.—SA2
White, J. A.—J3
Whittemore, W. L.—DA5
Wiese, Wolfgang—KA7
Wild, R. L.—G1
Wilets, L.—IA5
Williams, Dudley—WA10
Williams, Ferd E.—V11
Williams, Robert W.—FA6
Williams, Roscoe C.—SA9
Wilson, D. K.—SA3
Wilson, R. G.—F10
Wilson, Robert R.—X8
Winter, Rolf G.—U2
Witte, R. S.—V9
Wolfenstein, L.—O12
Wong, D. Y.—O2
Woods, A. D. B.—C3, K1, K2
Woodward, W. M.—BA1
Workman, J. B.—KA5
Wright, R. E.—YA8
Wu, C. S.—B4
Yankwich, Peter E.—GA11
Yen, J. T.—YA7
Yevick, George—U8, U9
Yntema, J. L.—XA5, XA6, XA7, XA8
Yodh, G.—VA7
Yoshiki, Hajime—MA11
Young, J. E.—MA1
Zaffarano, D. J.—B5, RA11
Zallen, R.—V10
Zauberis, D. D.—S9
Zavitsanos, Petros D.—GA11
Zeidman, B.—XA5, XA6, XA8
Zimmerman, R. L.—I5
Ziock, K.—X4, X5, X6
Zorn, J. C.—J2
Zucker, A.—UA8
Zwerdling, Solomon—T3

SALIENT FEATURES OF THE AAPT MEETING

WEDNESDAY AFTERNOON, JANUARY 27

2:00 P.M. New Orleans Room, Hotel New Yorker—Invited Papers

National Science Foundation Programs in Science Education

Program and Plans

C1. The Problem to be Solved. HARRY C. KELLY.
C2. Programs and Plans. BOWEN C. DEES.
Panel Discussion: Harry C. Kelly, Bowen C. Dees, Philip W. Hemily, Lyle W. Phillips, James G. Potter.

A Critique: GRANT O. GALE, JOHN C. JOHNSON, JAY W. BUCHTA, FRANK VERBRUGGE, ARTHUR G. ROUSE, A. B. WEAVER, MELBA PHILLIPS, AND ROBERT W. GREEN.

THURSDAY MORNING, JANUARY 28

9:00 A.M. Grand Ballroom, Hotel New Yorker—Invited Papers

"Space Science" Symposium

D1. Cosmical Electrodynamics. HANNES ALFVÉN, *Royal Institute of Technology, Stockholm, Sweden.* (40 min.)
D2. Electromagnetic Radiation from Extra-Terrestrial Sources. HERBERT FRIEDMAN, *Naval Research Laboratory.* (40 min.)
D3. Surface Properties of the Nearer Planets. E. J. ÖPIK, *Armagh Observatory, Northern Ireland, and University of Maryland.* (40 min.)
Panel Discussion: The panel will consist of the above speakers, Dr. Singer, and several other outstanding scientists who may be available for this meeting.

FRIDAY MORNING, JANUARY 29

9:30 A.M. New Orleans Room, Hotel New Yorker—Invited Papers

The New High School Physics Course—A Symposium Describing the Activities of the Physical Science Study Committee (PSSC)

F1. Introductory Remarks—Discussion of Objectives. HARRY C. KELLY.
F2. The Course and Its Content. FRANCIS L. FRIEDMAN.
F3. The Laboratory. URI HABER-SCHAIM.
F4. Films. ERIC ROGERS.
Discussion.

FRIDAY AFTERNOON, JANUARY 29

2:00 P.M. New Orleans Room, Hotel New Yorker—Invited Papers

F5. Teaching the New Physics Course. DAVID A. PAGE.
F6. The Teachers, The Students, and Their Reactions. GILBERT C. FINLAY.
F7. The Florida Experiment. GUENTER SCHWARZ.
F8. The College Reaction. ARNOLD ARONS.
F9. The University Reaction. NATHANIEL H. FRANK.
Discussion.

SATURDAY MORNING, JANUARY 30

9:30 A.M. New Orleans Room, Hotel New Yorker—Invited Papers

H1. The Use of the TV Image Orthicon in the Teaching of Physics. HARVEY E. WHITE.
Discussion.
H2. The Editor Discusses Our Journal. WALTER C. MICHELS.
H3. AAPT Activities and Affairs. FRANCIS W. SEARS.

11:00 A.M. Business Meeting of AAPT, New Orleans Room, Hotel New Yorker

Hotel Information

The New Yorker is the headquarters hotel. Reservations should be sent directly to Mr. Thomas Hurd, Front Office Manager of the New Yorker, in the manner directed below. Please tear off the attached and use as your room reservation blank. Be sure to specify the persons for whom reservations are being made. All rates quoted are for the room, and in the event of more than one person occupying the room the rate can be shared. If a third person is housed in the room, the cost of the extra "roll-away" bed will be added to the cost of the room.

If a room at the rate requested is not available, one at the nearest available rate will be reserved for you. Be sure to bring the confirmation slip with you as proof of your reservation. In fairness to others, please make a cancellation if your plans change. Unless otherwise requested, the hotel will hold reservations only to 6 P.M. of the day of your arrival. Check-out time is 3 P.M.

Hotel Rates

Hotel	Room and Bath for one per day	Double-Bed Room with Bath for two per day	Twin-Bed Room with Bath for two per day	Suites Living Room Bedroom and Bath for one or two per day
New Yorker 34th Street at 8th Avenue	$8–$14.50	$11.50–$18.00	$15.50–$20.00	$35.00 and up

NOTE: All rates subject to New York City 5% hotel room tax.

Tear Off

Tear Off

To: Front Office Manager
Hotel New Yorker
34th Street and 8th Avenue
New York, New York

A.P.S.

Please enter my reservation for a single / double / twin bedroom at approx. $..... to $..... per day for the 1960 A.P.S. Meeting. I / We plan to arrive..... and remain until .....

Print below persons in your party.

.....
Signature

.....
Address (Street or P.O.)

.....
Town or City and State

Preliminary Announcement of the 1960 Southwestern Meeting

In 1960 the Southwestern Meeting of the Society returns to its first home, The Rice Institute at Houston, Texas. The dates will be Friday and Saturday, March 4 and 5. The hotels that have set aside rooms for our members are the Shamrock-Hilton and the Warwick, both close to the campus of The Rice Institute. In writing to these, be sure to mention that you are coming to the meeting of the American Physical Society.

Deadline day is Friday, January 8, and abstracts are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York. *Please be careful to mark your abstracts for the Southwestern Meeting, as deadline for the Detroit Meeting arrives only a week later.*

Preliminary Announcement of the 1960 "March" Meeting

The 1960 "March" Meeting of the American Physical Society—so called because we have never yet been able to discover a short way of saying "the meeting which is devoted mainly to the Divisions of High-Polymer Physics, Solid-State Physics, and Chemical Physics"—will be held in Detroit, Michigan, on Monday, Tuesday, Wednesday, and Thursday, March 21–24. The Division of High-Polymer Physics expects to meet from Tuesday through Thursday; the others will begin on Monday and may (or may not) confine their papers to three days. The hotels which have set aside rooms for our members are the Park-Shelton, the Statler, and the Sheraton-Cadillac. In writing to any of these, be sure to mention that you are coming to the meeting of the American Physical Society.

Deadline-day is Friday, January 15, and abstracts are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York. *Please be careful to mark your abstracts for the Detroit Meeting, as deadline for the Southwestern Meeting arrives only one week earlier.*

1960 Topical Conference on Neutron Diffraction in Relation to Magnetism and Chemical Bonding

A Conference on Neutron Diffraction in relation to Magnetism and Chemical Bonding, sponsored by Oak Ridge National Laboratory, the Office of Naval Research, and the American Physical Society, will be held in Gatlinburg, Tennessee, April 20–22, 1960. Members desiring more detailed information should write to E. O. Wollan, Oak Ridge National Laboratory, Oak Ridge, Tennessee. Abstracts of contributed papers may be sent to E. O. Wollan (*not to the Secretary of the Society!*) and must reach him not later than March 1, 1960. *Abstracts must conform to the same regulations as are imposed on those submitted for general meetings of the Society; otherwise they will not be printed.* Take note that it is the prerogative of the management of the Conference to accept or decline contributed papers that are offered.

Second Topical Conference on Reactions between Complex Nuclei

A second conference on Reactions between Complex Nuclei will be held on May 2 and 3, 1960, at Gatlinburg, Tennessee. Any member of the Society who desires more detailed information should write to Dr. Robert S. Livingston, Oak Ridge National Laboratory, Oak Ridge, Tennessee. Abstracts of contributed papers may be sent to Dr. Livingston (*not to the Secretary of the Society!*) and must reach him not later than April 2, 1960. Abstracts must conform to the rules and instructions imposed on abstracts for the general meetings, else they will not be published in the *Bulletin*. Take note that the management of the Conference has plenary authority to accept or decline contributed papers that are offered.

Proceedings of the American Physical Society

Minutes of the Meeting Held at Washington, D. C. on April 30, May 1 and 2, 1959

THE 1959 Spring Meeting of The American Physical Society at Washington marked a breach in a short tradition and the probable end of a long one. The short tradition was that of using the Sheraton-Park Hotel for our headquarters and our sessions; the long tradition was that of scheduling our convention for the last three days of the week of which the National Academy of Sciences occupies the three days previous. Owing to the hotel situation at Washington, we were obliged to choose between breaking the short tradition and breaking the long one. In 1959 we took the former alternative, and our official hotels were the Willard and Raleigh downtown, while our session halls were rooms in the Willard and great Government auditoria in the vicinity of Pennsylvania Avenue and Fourteenth Street, and of course our old home at the National Bureau of Standards. In 1960 we shall take the other alternative, and regain the Sheraton-Park by shifting our congress to the same dates as those of the Academy: Monday, Tuesday, and Wednesday, with an extension into Thursday morning. I cannot say that I heard any outcry against inconveniences of the 1959 convention, and certainly they were by no means ruinous to the meeting, so well had the Local Committee coped with them; nevertheless it seems better to reconcentrate our sessions so as to bring all but a few of them under a single roof.

There were 453 contributed papers, a number greater by 11% than the previous record here or anywhere. There had to be seven simultaneous sessions all of the time, and an eighth on Thursday morning and afternoon to make place for a symposium on Space Exploration for which we deserve little of the credit though we were offered the privilege of coupling the name of the Society to it. On the programme figured also two speeches on the history of the cyclotron, motivated by the recent death of the lamented Ernest Lawrence; a half-day symposium entitled "Precise Neutron Cross-Sections"; and a half-day symposium organized by our Division of Fluid Dynamics. Other invited papers were fewer than we should have liked, because of the plethora of ten-minute papers.

The Dannie Heinemann Prize for Mathematical Physics was awarded for the first time at the banquet, and the prize winner, Murray Gell-Mann, gave a lecture at the meeting.

The banquet, held at the Willard Hotel, had an attendance which set a record (356) for the past several years: the after-dinner speaker was Lewis Strauss. The registration for the meeting amounted to 2082, quite a typical figure for our Washington meetings. The management of this convention was again, as for the past several years, in the extremely capable hands of R. D. Huntoon, ably assisted by W. R. Tilley, P. L. Reid, and other members of a Local Committee drawn from several of the institutions that conduct research and teaching of physics in the Washington area. The ladies' programme was admirably planned and executed by Mrs. A. G. MacNish.

Elected to Fellowship on April 29, 1959: Peter L. Bender, James E. Draper, Robert J. Finkelstein, Murray Gell-Mann, S. H. Koenig, David Lazarus, Ernest A. Lynton, Jules A. Marcus, Steven A. Moszkowski, George F. Pieper, P. J. Price, Robert A. Satten, Herman Statz, D. H. Stork, H. K. Ticho, J. Earl Thomas, Jr., Gottfried Wehner, and William J. Otting, Jr.

Elected to Membership on April 29, 1959: Harold J. Applegate, *Roy T. Arnold, *Atam P. Arya, *Adam Becher, William T. Biedler, III, H. K. Birnbaum, René R. Boulenger, William S. C. Chang, Jean P. Chapelle, Stewart G. Chapin, Richard R. Chasman, Q. Won Choi, William J. Crowe, *James H. DeLap, Murray Disman, Jack G. Dodd, William H. Dunham, *Marc R. Dupuis, *Joseph H. Eberly, *John E. Eby, David D. Elliott, Frederick J. Ewing, Janice S. B. Fain, Robert J. Fallon, *Walter L. Faust, Morris E. Fine, William C. Flanagan, George A. Frank, Jr., Robert A. Gibbons, *Claude M. Gillespie, *H. Peter Glockman, *Robert J. Goshen, Aaron P. Greifer, Albert F. Grenis, Thomas J. Grontkowski, *Fokion T. Hadjioannou, *Larry Haskin, *Roy C. Herndon, Roy J. Heyman, Bobby R. Hickman, William G. Hodgson, Mark Holzman, *Donald A. Jennings, Jack G. Kay, *Kenneth I. Kellermann, *John N. Kidder, *Harry J. King, Ronald C. Knechtli, *Joseph J. Kubis, *John H. Kusmiss, Richard P. Lagerstrom, Bertrand A. Landry, M. J. Laubitz, *John Lee, *Sook Lee, *Sherwin S. Lehrer, Thomas B. Light, Daniel C. Lu, *Henry J. Lubatti, Harry Luhrs, *Peter M. Maas, Wilbur Marcus, James A. Maxwell, Paul Mazur, Graham J. McCallum, Michael E. McCormick, Paul H. Metzger, *Karl-Wolfgang Michel, Dolphus E. Milligan, John J. Miyata, Wolfgang E. Moeckel, *Charles Nissim-Sabat, Raymond P. Pecoraro, Robert L. Peercy, Jr., *Philip A. Pincus, Roger A. Potts, W. Bruce Pruitt, *Robert Ta-Pang Pu, F. Joseph Reid, *Roderick V. Reid, Jr., Thomas T. Reynolds, *John S. Rigden, *David C. Rorer, Stephen Rosen, Morton Rosoff, *J. Reece Roth, *Morton H. Rubin, Jack Rufenacht, *Steven J. St.-Lorant, John F. Scoles, *William J. Scouler, D. Richard Sears, *Marion L. Shaw, *Bruce M. Shoffner, *Louis Shotkin, *Ed N. Sickafus, *Albert J. Sievers, III, P. Scott Smith, Jozef Spaepen, *Melvin S. Spielberger, *Michael H. Spring, Joseph Sternberg, Jackson S. Stroud, John J. Szalay, Andrew Tarasevich, C. Kenneth Tucker, Ryuzo Ueda, *Jack R. Vaill, Jacques Valentin, William L. Vault, *Joseph B. Waltrich, Emanuel M. Weiss, John H. Ward, Stacy B. Watelski, *John S. Waugh, Richard F. Wenzel, Nils F. Wikner, John E. Wilford, *Clayton D. Williams, Man-Chong Wong, A. David B. Woods, *E. James Woods, Theodore Y. Wu, *John T. Yanagi, and *Harry L. Yanger.

* Student.

Errata Pertaining to Abstracts B9, F10, JA2, NA3, NA4, NA13, NA14, PA13, T13, and U4 of the 1959 Washington Meeting

(Series II, Vol. 4, No. 4)

B9, by E. M. Horl. The last line should read "crystal growth ([111] direction approx $\perp$ temperature gradient)."

F10, by L. Th. Rietjens and O. Bilaniuk. In lines 6 through 10, instead of "The Ti^{47} ground state $ln=3$ transition is $\sim$30 times more intense than the transition to the 0.160-Mev first excited state for angles $\theta_{lab}=5°$ to 90°. This result favors a $J=\frac{7}{2}$ assignment to Ti_0^{47}, contrary to the accepted value of $J=\frac{5}{2}$," read "The Ti^{47} 0.160-Mev state $l_n=3$ transition is $\sim$30 times more intense than the transition to the Ti^{47} ground state. This result favors a $J=\frac{7}{2}$ assignment to the 0.160-Mev state of Ti^{47}."

JA2, by R. L. Moore. In line 3, instead of "$\partial p/\partial r]_0=-H_0^2/4\pi r_0$" read "$[(1/\rho)\partial p/\partial r]_0=-H_0^2 r_0/4m$." Also, in the last line, instead of "$-(r/2\pi m)(\dot{H}H)$," read "$\{-[r/2m](\dot{H}H)\}$."

NA, by P. A. Flournoy, R. S. Tickle, R. W. Fast, and W. D. Whitehead. In the last two lines, instead of "Li σ int (11–60 Mev) 0.090 Mev-barn; N_2, σ int (13–55 Mev) 0.165 Mev-barn," read "Li σ int (11–50 Mev) 0.076 Mev-barn; N_2, σ int (13–50 Mev) 0.116 Mev-barn."

NA, by L. B. Aull, G. C. Reinhardt, and W. D. Whitehead. In the next to the last line, instead of "30 Mev is about 5%" read "30 Mev is about 10%."

NA, by N. Nath, S. S. Malik, M. A. Rothman, and D. M. Van Patter. In line 6, instead of "Ti^{48} 0.99, 1.32, 1.48," read "Ti^{48} 0.99, 1.32, 1.44." Also, the last sentence should read "The γ-ray branching ratio measured for the second level of $Zn^{64,66,68}$ is in agreement with some of the recent results from radioactive decay studies.[2]"

NA14, by S. S. Malik, C. C. Mandeville, N. Nath, M. A. Rothman, and D. M. Van Patter. In line 11, instead of "Se: 0.90, 1.13, 1.78," read "Se: 0.90, 1.13, 1.73."

PA13, by Y. W. Kim, R. Kaplan, and P. J. Bray. In line 10, instead of "more than 91 hyperfine lines" read "more than 19 hyperfine lines."

T13, by James H. Foote, Ernest H. Rogers, Herbert M. Steiner, Clyde Wiegand, Tom Ypsilantis, and Owen Chamberlain. In the heading of the fourth column of Table I, instead of "$\epsilon\bar{P}_2$" read "ϵ/P_2."

U4, by Kenneth T. Bainbridge and Elizabeth Baker. In line 3, instead of "$\lambda(BeS)=5.2_8\pm0.6\times10^{-4}\,\lambda(Be)$" read "$\lambda(Be)-\lambda(BeS)=5.2_8\pm0.6\times10^{-4}\,\lambda(Be)$."

MEETINGS AND DEADLINES THROUGH SUMMER 1960

Place	*Meeting dates*	*Deadline date*
New York	January 27–30	past
Houston	March 4–5	January 8
Detroit	March 21–24	January 15
Washington	April 25–28	February 12
Montreal	June 15–17	April 8

Abstracts for these meetings are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. The inclination of our members to wait until the last minute too often results in waiting *beyond* the last minute, and this is by no means always the fault of the postoffice. All abstracts that arrive in envelopes postmarked on deadline day, and all abstracts that arrive in envelopes postmarked on or near the West Coast on the day before deadline day, are instantly rejected; but even those that are mailed a day or two earlier are by no means sure of making the grade. A special-delivery stamp is usually useless and often worse than useless. It is a good idea for our members to put their abstracts into United States mailboxes themselves, instead of entrusting them to company or university mail collectors; we often get abstracts with covering letters dated two days earlier than the postmark. Telegraphed abstracts are unacceptable. *The privilege of contributing papers to meetings of The American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

TOPICAL CONFERENCES (see page 93)

Place	*Condensed title*	*Dates*	*Deadline date*
Gatlinburg	Neutron Diffraction	April 20–22	March 1
Gatlinburg	Reactions between Complex Nuclei	May 2–3	April 2

Abstracts for these Conferences are to be sent to the respective addresses given in the respective announcements on page 93, and NOT to the office of the Society. They must conform to the same rules and instructions that are imposed on the abstracts for general meetings, else they will not be published in our *Bulletin*.

RULES AND INSTRUCTIONS FOR THE PREPARATION OF ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten; ***one must be an original***, the other may be an original or a carbon copy. ***Carbon copies will not be accepted in lieu of originals:*** they smear. ***Abstracts must be double-spaced:*** single-spaced manuscripts are too crowded to permit the editorial markings to be made with ease and clearness. ***Each abstract must be confined to a single page:*** if it is too long for a single page it is too long to be printed. If we receive an abstract typed on two pages, we print only its first page. ***Write each abstract as a single paragraph:*** the suppression of paragraphs costs time and labor to the editors. ***Do not use very thin paper:*** a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. The American Institute of Physics will bless you if you type first the title of your abstract in lower-case with capitalized initials, then your name in capitals, then the name of your institution in lower-case underlined with capitalized initials. It is a pleasure to report that those who qualify for this blessing are increasing in number but are still quite a bit short of 100% of the total. Issues of the ***Bulletin*** are always appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Program. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

It has now become an expensive business to make any change in an abstract, even the smallest, after the abstract has gone to press. By order of our Council "A change in an abstract will be permitted only at the discretion of the Secretary or his deputy, and only if TEN DOLLARS is enclosed with the letter in which the change is requested." As heretofore, an abstract will not be withdrawn from proof unless the asker sends ten dollars with his request.

New Instructions

(*a*) *If it is wished that two abstracts be scheduled consecutively, write on the first "To be scheduled before abstract ..... by ....." and on the second "To be scheduled after abstract ..... by ....."*

(*b*) *If a member insists that his paper be scheduled for a particular day, this usually will entail that it be added to a session to which it is irrelevant.*

(*c*) *The Council has empowered the Secretary and his deputies to count a footnote either as ten words or as the actual length in words of the footnote, whichever is the greater figure.* This authority will be used in dealing with lengthy footnotes consisting of prolix and redundant information about the provenience and sponsorship of abstracts.

The American Physical Society

OFFICERS OF THE SOCIETY FOR 1959

President	G. E. UHLENBECK	University of Michigan
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Elected Members now on Council: S. K. Allison, N. F. Ramsey, Walker Bleakney, W. K. H. Panofsky, W. A. Fowler, Charles Kittel, Harvey Brooks, and Charles Hard Townes.

Local Secretary for the Pacific Coast	W. A. NIERENBERG	University of California, Berkeley
Deputy Secretary	W. W. HAVENS, JR.	Columbia University

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